

TECHNIQUES IN SLIPFORM PAVING AND
CONTINUOUSLY REINFORCED CONCRETE
PAVEMENT CONSTRUCTION.

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BY

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JHRP

JOINT HIGHWAY RESEARCH PROJECT
PURDUE UNIVERSITY AND
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TECHNIQUES IN SLIPFORM PAVING AND CONTINUOUSLY
REINFORCED CONCRETE PAVEMENT CONSTRUCTION

TO: J. F. McLaughlin, Director
Joint Highway Research Project

March 24, 1971

FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-67E

File: 9-11-5

Attached is a Final Report titled "Techniques in Slipform Paving and Continuously Reinforced Concrete Pavement Construction". This report has been authored by Mr. O. T. Olateju, Graduate Assistant in Research on our staff, under the direction of Professor John A. Havers. The research was approved on November 18, 1969, under the title "An Investigation Into Improved Pavement Slipforming Techniques".

The purpose of this project was to examine current techniques for slipform paving and for installing reinforcing steel in continuously reinforced concrete pavement constructed by slip-forming. Although slipforming techniques in use today were found to be generally satisfactory and to produce good quality pavements at lower cost than conventionally formed pavements, several problems were also noted which are discussed in detail in the report. Problems with installing the steel in continuously reinforced concrete pavements are also discussed and recommendations for the ISHC relative to construction using slipform paving and techniques for steel reinforcement installation are made.

The Final Report is presented for acceptance as fulfillment of the objectives of this research.

Respectfully submitted,

Harold L. Michael

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Final Report

TECHNIQUES IN SLIPFORM PAVING AND CONTINUOUSLY
REINFORCED CONCRETE PAVEMENT CONSTRUCTION

by

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Acknowledgement is given to several contractors in Indiana, Iowa, North Dakota, Illinois, Minnesota and Wisconsin, state highway officials, equipment manufacturers and many private individuals whose contributions have made this research successful.

Finally, the author wishes to express his gratitude to the Joint Highway Research Project for providing funds for the research.



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ABSTRACT

OLATEJU, Olubayo Timothy. MSCE, Purdue University, January 1971. Techniques in Slipform Paving and Continuously Reinforced Concrete Pavement Construction. Major Professor: Dr. John A. Havers.

This research was sponsored by the Joint Highway Research Project at Purdue University. Its purpose was to examine current techniques for slipform paving and for installing reinforcing steel in continuously reinforced concrete pavement which are constructed by slipforming. In performing the study, contacts were made with various highway officials, contractors, equipment manufacturers and private individuals. The information thus obtained included descriptive literature, photographs and time lapse movies of the construction operations.

The report is divided into four major parts. The first of these reviews the development, acceptance, and usage of the slipform paving technique. It also discusses ancillary highway paving activities, other than the construction of the primary traffic-supporting pavement, where slipform paving techniques have proved applicable. Procedures for checking the pavement depth, texturing and measuring the surface smoothness of a slipformed pavement are also discussed.

The second part describes the various methods for installing both mesh and rebars for CRC pavements. It includes a review of the experiences of the several states in which these techniques have been used, based on information from a questionnaire and from telephone conversations.

The third section of the report describes eight field studies which were made during the summer of 1970 in five different states. These observations were recorded by time lapse photography. A description of the time lapse technique and the manner in which it was applied to this study is also provided.

The fourth part consists of an evaluation of the findings and the conclusions drawn therefrom. This part also includes recommendations for action and for further study.

INTRODUCTION

Overland transportation routes have always been of importance to civilization. The construction and maintenance of city streets and public highway is today one of the most important and expensive single improvements that a community undertakes. An ideal pavement for surfacing these roads and streets would possess various desirable characteristics. It must be sanitary; smooth, but not slippery; easy to repair and clean; noiseless; durable; and it must be constructed at an acceptable cost.

Alternative methods of pavement construction should receive adequate attention in the planning stage, since they can materially affect the value of the finished product (1)¹. Within the last two decades, the procedures and equipment for the construction of concrete pavements have undergone revolutionary changes. The old methods of construction, which involved the use of various types of manually adjusted machines and a great deal of costly hand labor, are giving way to methods which make use of more versatile and more sophisticated machines to

¹Numbers in the parenthesis indicate reference number in the list of references

eliminate much of the hand labor formerly required. These new machines, one of which is the slipform paver, have greatly increased the production of quality pavements at favorable costs.

The slipform paver depends upon the ability of low-slump concrete to remain in place, without the aid of pre-erected side forms, during placement, consolidation, and surface finishing. This method of constructing portland cement concrete pavements has been acclaimed as both economical and effective (2). A fuller utilization of slipforming will be realized as mechanized methods are perfected for placing reinforcing steel in continuously reinforced concrete (CRC) pavements.

A CRC pavement differs from the conventionally reinforced pavement in that it is made without expansion or contraction joints. The slab thus functions as a unit its entire length (3). This continuity is achieved by the lapping of steel; it makes the pavement safer, smoother and quieter (4). CRC pavement reinforcement usually consists either of deformed bars or of bar mats which are up to $2\frac{1}{2}$ times as heavy as the distributed steel in conventional pavements. The accurate setting of this heavy continuous reinforcement presents a problem, whose solution has not yet become an established construction routine (5). In some cases the steel has been set on chair supports which are left in place when the concrete

is poured. In other cases the concrete has been placed in two lifts, with the steel "sandwiched" between them. These methods of placing reinforcement have not been entirely satisfactory (6,7), but they have survived because of a lack of accepted alternatives. The paving contractor would like to be able to place the concrete in one lift while avoiding the tedious and expensive process of first setting the reinforcement on chairs. This has led to the development of mechanical methods for steel placing, whereby machines can eliminate most of the hand labor which is characteristic of both chair supports and sandwiching. All but one of these machines are adaptable to slipform paving.

Although these machines have passed the development stage and are now commercially available, they have yet to win widespread acceptance among the states. However, it is the opinion of the author that mechanical steel placement will rapidly become the predominant method of concrete pavement construction.

This four-part report starts with a review of the development, acceptance and usage of the slipform paving technique. It discusses ancillary paving activities where the slipform paving technique has proved applicable. It also discusses procedures for checking pavement depth, texturing, and measuring surface smoothness of a slipformed pavement. The first part is concluded with a look into the future of the slipforming technique.

In the second part, various methods for installing both mesh and rebars for CRC pavements are discussed. The reported experiences of various states in which these techniques have been used are also discussed.

The third part of the report describes eight field studies which were performed during the summer of 1970 in five different states. These observations were recorded on time lapse movies. A description of the time lapse technique and the manner in which it is applied to this study is also included.

The fourth part is devoted to an evaluation of findings, conclusions, and recommendations.

PART I
SLIPFORM PAVING

PART I - SLIPFORM PAVING

The slipform paver is essentially a travelling form that extrudes a ribbon of concrete on the prepared subgrade. The paver controls the depth of concrete and consolidates it as part of the placement procedures (2). Because it spreads, vibrates, forms and finishes concrete in a continuous operation, the slipform paver reduces both equipment and manpower requirements. It eliminates fixed forms, replaces several of the machines found in the conventional paving train, and cuts the size of the paving crew in half (8).

Development of the Slipform Paver

Prior to 1949 all concrete pavements were constructed by a "paving train" which travelled on side forms. However, in 1947, Mr. J. W. Johnson of the Iowa State Highway Commission, speculated on the feasibility of removing the side forms before the concrete had set. It was suggested that a good-quality concrete, if properly consolidated, would stay in place without running down the grade (9). A travelling form, or "slipform", could be used to define the placement limits for the fresh concrete.

The next step was to investigate the feasibility of slipform paving by actual field trials. A small pilot

model, capable of placing a continuous layer of concrete 18 inches wide and 3 inches thick, was built and tested in Iowa in 1947. This model proved so successful that a larger unit was built and tested in the following year. This second unit was capable of placing a layer of concrete 3 ft wide and 6 inches thick. The next version, which at that time was considered to be a full-size unit, was built in 1949 and used to pave experimental roads in Iowa. This machine extruded a continuous strip of concrete 10 ft wide and 6 inches thick, and was equipped with 11 ft long trailing side forms (2).

This first practical slipform paver was later modified in some respects, including adding the capability for self-propulsion. However, it was recognized that still further development was necessary if it was to realize its full potential. This task was viewed as the responsibility of those engaged in building and using concrete paving equipment, rather than a proper function of a state highway department (9). The slipform paver therefore became commercialized and crawler tracks, vibrators, tamping bars, and finishing belts were incorporated into its basic design. The first commercial unit was put in service in 1955, and since then, numerous manufacturers have marketed slipform pavers. The improvements resulting from this industry effort have contributed to the use and acceptance of the slipform pavers by many states.

In many states, slipform pavers were first used on small experimental sections. Kentucky used slipform pavers to widen existing roads, as shown in figure 1 (2). Slipform paving in Iowa spread from secondary to primary routes and finally to interstate highways. Pioneering jobs were also undertaken in California, Colorado, and Oklahoma. These included full-width, single-pass paving of sections 36- to 48-ft in width, and the incorporation of reinforcing mesh in the concrete slab in conjunction with slipform paving (9). Many state highway officials now believe that the slipform paver lays a smooth concrete pavement of equal or better quality than the conventional method of paving, and does this at a lower cost. The development of methods of incorporating reinforcing steel into a slipformed pavement has also helped the rapid acceptance of the slipform paving technique. More and more states now give contractors the option of either slipform or side form pavings, and under these circumstances the contractor will increasingly elect slipform paving.

The acceptance of the slipform paving technique is evidenced by the answers to a questionnaire sent out in 1968 by the Portland Cement Association to the 50 states and the District of Columbia. Nine states used only slipform construction; 25 states used both slipform and conventional formed construction, with 44.5% of the projects using slipform method; and nine states used only



Figure 1

Slipform Paver Being Used to Widen a Road in Kentucky

conventional formed paving. These statistics applied only to paving done in 1968. Six states and the District of Columbia reported no paving in 1968, and no information was available from Alaska (10). Today 44 states permit slipform paving and 39 have projects completed or under contract by this method. The slipforming technique has also spread northward into Canada, and across the seas to France and Great Britain (9). One can predict that by the end of this decade, "conventional" side form paving will have become the "unconventional" paving method!

Advantages of Slipforming

Advantages in the use of slipform paving technique range from savings in time and manpower, and fewer job management problems, to improved capability of producing high quality, smooth riding concrete pavements at lower costs.

Reductions in Construction Time

The aim of every paving engineer and contractor is to provide the public with high quality pavement surfaces at reasonable cost. The slipform paver has helped to accomplish this objective. Construction of more than a mile a day of 24 foot pavement is commonplace, and in one instance a contractor with no previous experience in the use of a slipform paver laid almost 2½ miles of plain

concrete in one day (11)! This high rate of production permits considerable savings in construction time.

Reductions in Labor Requirements

The slipform paver has also drastically reduced the size of the paving crew. Some contractors have reported a reduction of 15 to 30 men when the slipform method is compared with the old form set method (12,13). This manpower saving has resulted from the elimination of the entire form setting and form moving crew, and the elimination of most of the finishing crew. With proper concrete slump and consolidation, the slipform paver places the concrete slab as a nearly finished surface. Only a few men are needed to fill in tears and repair other surface imperfections.

Reductions in Equipment Requirements

The slipform paver has reduced the number of machines required on a paving train. One slipform paver takes the place of from three to four conventional concrete paving machines (13). Because of this, it reduces the capital investment required for a paving equipment spread. For the average paving project, a conventional spread of paving machines, including forms and related handling equipment, will require an investment of from \$200,000 to \$250,000. A slipform paver which will perform the same operations as the conventional spread will cost between \$120,000 and \$130,000.

Another major area of savings attributed to slipform paving results from the elimination of side forms and all labor associated with their setting and removal. Material, labor, and supervision for setting and moving of these forms for conventionally paved 9-inch concrete pavement will cost between \$0.16 and \$0.19 per square yard (14).

Simplified Job Management

With a substantial reduction in the quantities of equipment and manpower, job management problems are greatly reduced by slipform paving. The smaller amount of equipment also reduces the field repair and maintenance problems. In highly unionized areas, the smaller work force will result in fewer union difficulties and problems for management. In fact, the slipform paver simplifies the entire operation and confines it within a shorter working period and space. All paving elements can, therefore, be controlled and supervised more effectively.

Other Advantages

Several contractors and highway officials have reported less concrete waste when slipforming. This feature is primarily attributed to better control of subgrade finishing (14). Bid reductions attributable to slipform paving amounting to as much \$0.50 per square yard have been reported in Colorado (15,16). The experienced contractor can now meet any current concrete paving

specification with the slipform method if he is given the opportunity to do so. The slipform technique has been proven; it only needs more universal acceptance.

Types of Slipform Pavers

All slipform pavers in current use are similar in several respects. They all perform the functions of spreading, vibrating, striking off, consolidating and finishing a pavement to the prescribed cross-section and profile. They can all produce an acceptable riding surface with a minimum of hand work. Many slipform pavers use the principle of trailing forms, some receive concrete from one or more mixers at a time, and most can travel on crawlers at rates of 10- to 30-fpm.

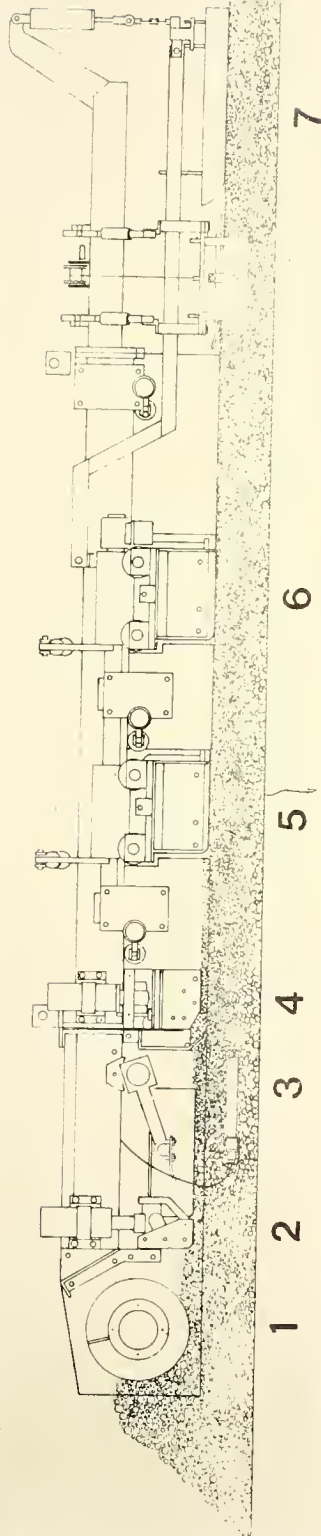
Despite these similarities, there are differences between the pavers offered by the various manufacturers, and even between the models offered by a single manufacturer. Some contractors prefer to build their own equipment instead of using the commercially available units. It is believed that the near future will see the development of more slipform pavers with complete automatic controls. This will remove most human errors and produce smoother and more durable pavements at still greater economies.

Construction Machinery Inc. (CMI) Paver

The CMI company of Oklahoma City manufactures three types of slipform pavers. These consist of single lane and dual lane autograde pavers, and the autograde 'CC' slipform paver. All three types are mounted on four heavy plate crawler tracks and can be converted easily from slipform pavers to either a grader or a spreader unit. They are all equipped with automatic controls and adjustable screw-mounted sensor-tracing units. They all feature a so-called "continuous conditioning" which, according to the manufacturer, will ensure uniformity of the finished slab, greatly increase the quality of the finish, and eliminate subsidence behind the machine. The single lane autograde can be used to pave ramps and median strips, and is claimed to lay a slab requiring minimum finish at speeds of over 50 fpm. The other two models have infinitely variable travel speeds within the range of 0- to 240-fpm, although their regular paving speeds will be between 10- to 20-fpm. The pavers do not use trailing forms, but instead have side forms which can be easily detached. Figure 2 shows the basic components of a CMI slipform paver. .

Gomaco Paver

The Gomaco Corporation of Ida Grove, Iowa, manufactures one model of slipform paver, the C-550. The main features of this slipform paver are its curb and



1. **Concrete Spreader Auger** blends, mixes and proportions the concrete.
2. **Primary Concrete Feed Meter** proportions the volume of concrete entering the internal vibrator compartment.
3. **Internal Vibrators** blend and consolidate the mix.
4. **Secondary Concrete Feed Meter and Grout Circulator** control the volume of mix passing through the primary oscillating finisher and circulates grout thoroughly through the aggregate.
5. **Primary Oscillating Extrusion Finisher** helps consolidate the mix while shaping and finishing the slab.
6. **Final Oscillating Extrusion Finisher** works in conjunction with the edgers to form and shape the finished slab to the exact profile of the finished highway.
7. **Floating Fine Surface Finisher** produces a near-perfect slab surface requiring the very minimum of finishing.

FIGURE

Basic Components of a Paving Machine

gutter attachments and the ease with which it can be lengthened or shortened by 4-, 8-, or 12-ft increments from 12- to 84-ft. It is mounted on four crawler tracks and is powered and controlled from the operator's console. It can be used to pave ramps, can negotiate radii as small as 250 ft and can pave at speeds of up to 15 fpm. Figure 3 shows a Gomaco slipform paver's integral curb attachment.

Guntert and Zimmerman (G & Z) Paver

Equipment manufactured by G & Z of Stockton, California, has been used most extensively on the west coast, where it has been observed to produce extremely smooth surfaces. The company manufactures different sizes of slipform pavers which are capable of paving from 12- to 48-ft slabs in one pass. The machines can travel up to 36 fpm, negotiate radii of 500 ft and pave slopes and superelevations up to 6%. They currently use no trailing forms, (although earlier models were equipped with trailing forms 120 ft long), and can be fed from different locations, front or sides. The manufacturer claims that the 24 ft machines can empty an 8-1/4 cu yd truck in 30 seconds and can handle an average of better than one truck per minute.

The machines are equipped with electronic sensors for automatic grade control. Specially designed, spring-loaded header forms are used to facilitate easier starting of daily operations and to prevent the machine from "bottoming out" at high spots on the subgrade.



Figure 3

no Attachment of any form of armor

Heltzel Paver

The slipform paver which is manufactured by the Heltzel Steel Form and Iron Company of Warren, Ohio, consists of two sections which are pivotally connected at their centers. The front section can be steered on curves, ramps, and transitions. It is mounted on four crawler tracks and the manufacturer claims that it can negotiate radii as small as 150 ft. The machine can be equipped with sensing units to automatically control elevation from grade wires. Visual crown control is mounted on the operating panel, and hydraulic control of screed and extrusion pan allows instant crown change. The machine can pave at the rate of 20 fpm, handle pavement widths from 12- to 28-ft, and lay pavement thicknesses of up to 12 inches. Figure 4 shows the main features of a Heltzel slipform paver.

Johnson Paver

This machine is relatively a newcomer to the market. A pilot model was used in 1963 and the commercial model was scheduled to be available before the end of summer 1970. The paver was initially designed for fast set-up, short-run jobs on urban streets and roads, or approach work on interstate sites. It is expected to be able to pave at speeds of up to 25 fpm. It has electronic controls for alignment, surface elevation, and cross-slope, all controlled from a single wire. This electronic control ensures even height and uniform surface smoothness.

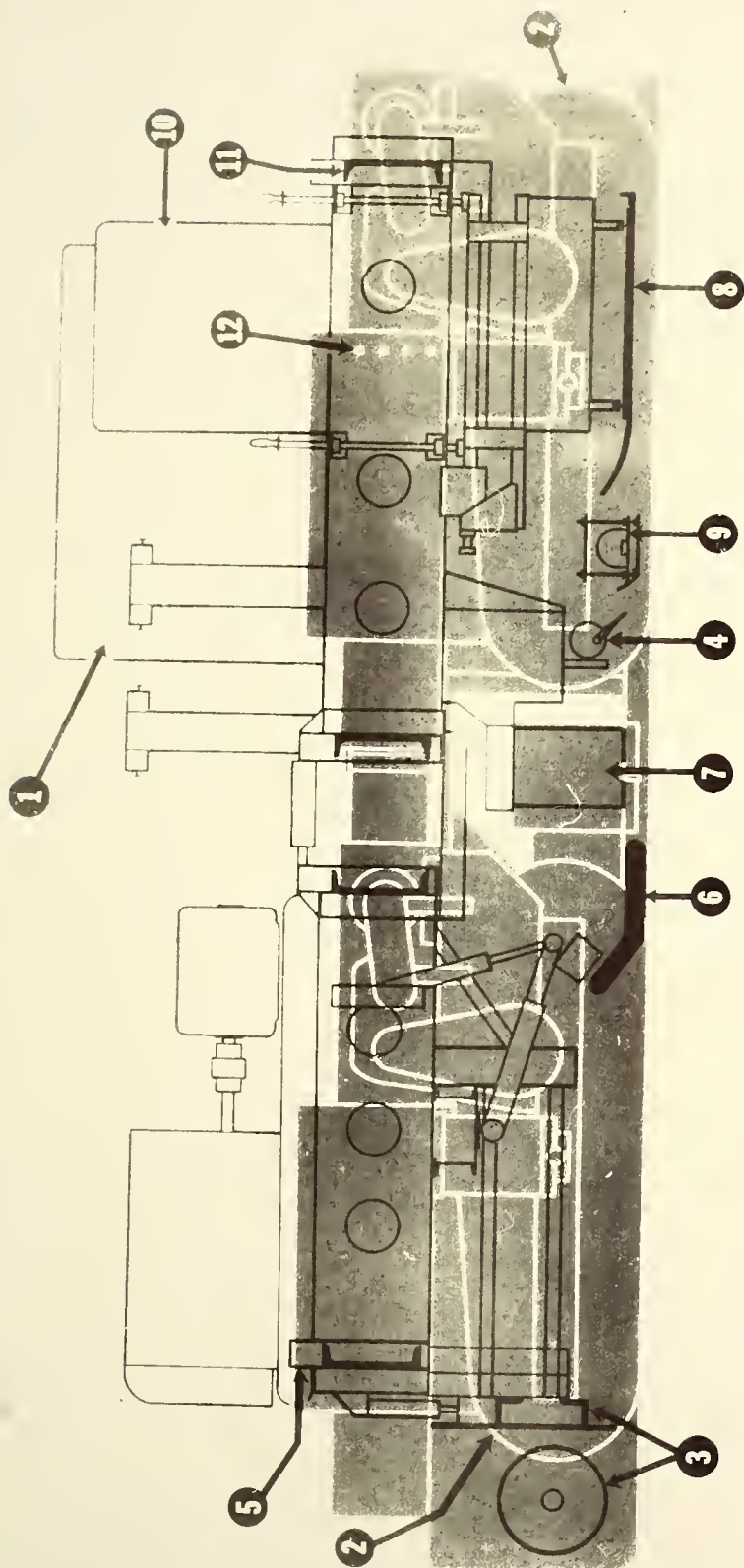


Figure 4

Basic Components of a Heltzel Slipform Paver

1. Silicon Controlled Rectifier Drive
2. Bogied Tracks
3. Spreading Screws
4. Automatic Elevation and Steering Control
5. Tie bar Installer
6. Spud Vibrators
7. Oscillating Screenshot
8. Extrusion Pan
9. Longitudinal Joint Installer
10. Diesel Engine
11. Hydraulic Frame
12. Vertical Track Adjustment

Rex Chainbelt, Inc. Paver

This company is located in Milwaukee, Wisconsin. It manufactures slipform pavers which can be used to pave 24- to 48-ft widths. It also offers a smaller machine for slip-forming ramps and other variable width sections. The pavers can easily negotiate a radius of about 200 ft, and have been used on slopes of up to 30 degrees. They travel at speeds of up to 30 fpm. The big machines have electronic crown change capabilities. At the option of the contractor, all machines can be equipped with electronic sensing devices. The company is presently developing a paving unit in which an operator can infinitely adjust the cam ahead of time to eliminate or add crown before or after paving a ramp. It is also developing a multi-directional paver which can vary its paving widths from 12- to 48-ft by rotating around a vertical plane. This machine, it is believed, will meet the needs of both the small and the large contractor because it will be able to grade and pave at any desired width.

The Rex Chainbelt pavers use trailing forms with recommended lengths of 25- to 30-ft. They have been used extensively in the United States and Canada and in many overseas countries. Figure 5 shows the new Rex STR paver which is capable of paving slabs up to 48ft wide.

Other Pavers

The trend in the slipform market is towards machines with automatic guide wire controls which are capable of



Figure 5

Rex's STR Paver (Capable of Paving up to 48 ft. in One Pass)

paving widths up to 36- to 48-ft. The R. A. Hanson Company of California has developed a slipform paver, model H S - 24, which uses automatic control for grade and level. The Blaw-Knox Company has four slipform pavers which have been used in California. These machines, according to their manufacturer, can pave both 24- and 36-ft pavements and can be converted to 12-, 24-, 36- or 48-ft widths in about 4 hrs. They pave at speeds of up to 20 fpm with travelling speeds of up to 60 fpm.

Some contractors, such as Western Contracting Company, have built their own equipment to standards which are competitive with those of the commercial pavers.

Elements of Slipform Paving

The importance of coordinating the paving process has been emphasized with the advent of slipform paving. The ability of this method to produce a pavement with a smooth, high quality surface is highly dependent on the preceding construction processes. The normal sequence includes the stabilization of base material for the pavement foundation, production of concrete and its delivery to the paver, the placing of the concrete to line and grade, and the finishing and texturing of the slab surface.

Subgrade and Subbase Preparation

The purpose of a pavement is to provide a smooth, durable surface over which vehicles may travel. Its performance is affected by the characteristics of the underlying subbase

and subgrade (17). The accurate construction of these foundation layers of the pavement is of critical importance to the paving operation.

Subgrade

The subgrade should be strong, stable and well drained. Further, it should maintain these properties throughout the years of pavement service. Gravel roads which have been used for some time can sometimes be paved with little additional preparation. In general, however, careful preparation of the subgrade will be required in advance of paving. This preparation is intended to produce a subgrade with the desired profile and section, and with strength properties such that it will function as a stable foundation for the overlying pavement layers.

The process of subgrade preparation involves scarification of the upper subgrade layers to a depth of several inches, plus a general re-shaping. These steps are usually performed by motor graders, although more specialized units are also available. Some movement of the scarified material is required, both along the centerline and transversely. The material is placed and compacted in general conformance with the required final subgrade elevation (18). This initial subgrade preparation minimizes any tendency for longitudinal pavement cracking or unevenness from subsequent subgrade settlement. Adequate inspection must be performed during construction to ensure that the specified densities and moisture contents are actually produced in the subgrade (17).

The subgrade is then trimmed to final grade within the specified tolerances by a subgrade trimmer. This machine maintains the proper grade by electronically 'sensing' the position of grade wires which have been preset along the route. The next step can be the construction of a subbase layer, or the pavement may be laid directly on the subgrade. The choice will primarily depend on the part of the country in which the construction is taking place.

Subbase

An accurately graded, stable subbase is essential in slipform paving. Only in this way is there assurance of obtaining a smooth pavement slab of proper depth. However, the subbase finishing operation for slipform paving requires construction techniques which are different from those normally used when pavements are constructed with sideforms. The subbase for slipform construction must be constructed in advance of paving operations and without the use of previously set paving forms as guides (19).

A subbase provides additional strength in the pavement structure, and can prevent mud pumping when conditions are such that this hazard exists. The subbase also performs several functions during the paving process. It has been used in side form paving as a stable base to anchor forms and dowel baskets, and to ensure proper slab thickness. It is the key to successful slipform paving, since it provides a firm and accurate base on which to operate the paver. If

the slipform method of paving is to be used successfully, with a minimum overrun of concrete, accurate subbase control is essential (17,19).

The accuracy to which a subbase can be shaped is influenced by its maximum size of aggregate. The subbase materials can be aggregates which meet the specified gradations or, where these materials are scarce, lower quality soils can be treated with cement or other additives to improve their properties. Once a subbase has been compacted and finished approximately to grade and crown, it can be given its final compaction and trimming by one of the previously described subgrade trimmers. These electronically-controlled machines, under suitable conditions, can trim the subbase to tolerances of $\pm 1/8$ in. (see Figure 6). Some states, Indiana included, prohibit the contractor from hauling over a finished subbase. This prohibition, although well intentioned, is of questionable wisdom. The use of the base as a hauling surface will facilitate the contractor's operations, and the savings realized thereby may more than offset any damage to the base.

Production and Control of Concrete

Batch-to-batch uniformity in the concrete used in slip-forming is also essential. The concrete slump and workability must remain consistent if a smooth slab surface is to be produced with a minimum of hand finishing.



Figure 6

Subgrade Trimmer Used to Trim a Base Course

Present Methods of Production

Accompanying the transition from sideform paving to slipform paving, there has been a change in the method of producing paving concrete. The former method, wherein dry batches were brought on-site to small travelling mixers, has been superseded by mixing in large stationary plants. By the beginning of 1969, approximately 80% of all concrete used for highway paving was being produced in these central-mix plants. A 1968 study indicated that about 86% of the concrete used on slipform projects was produced in central mix plants (10).

The central mix plants which are in use today are transportable and highly productive. Several of the plants in current use can produce up to 600 cu yds per hour and can be moved from one location to another and set up in a matter of hours. Because of their high rates of production, the central-mix plants require better control than do their dry batch counterparts. Bins and conveyors have been modified to minimize degradation and segregation. The coordination of batching cycles and bin gates has been improved to obtain optimum blending of ingredients before mixing. Cement silos have been redesigned to achieve better charging and batching rates. Fully-automatic batching and mixing controls are now used to ensure uniformity and quality in the concrete produced (20).

The central-mix plants may be either contractor-owned or commercially operated. Contractors have reported

problems with the concrete supplied from commercial ready-mix plants (21). These difficulties may be attributable to inherent inadequacies in the plants or to defects in their operation. A worn or broken blade in a mixer makes a great deal of difference in the concrete that comes out of the plant. When concrete for slipform paving is to be purchased commercially, the plant should be inspected periodically to ensure that all operating units are in good condition. Similar inspections are in order if the contractor elects to purchase and operate his own central mix plant.

One factor involved in the production of quality concrete is the mixing time. This item has been a point of controversy between contractors and state officials, particularly so since the central-mix plants have come into use. The Bureau of Public Roads has recommended that the mixing time for central-mix concrete should be based on performance testing. If a proper blending of materials is achieved during charging, the mixing time may be as little as 40 secs. Where mixer performance tests are not made, minimum mixing time should be 75 secs (22). The state of Indiana requires that a mixing time for on-site mixers of not less than 50 secs; this time should not be less than 90 secs when the mixer is not equipped with an approved timing device (23).

Each test of mixer performance should be based on three concrete samples taken from the mixer. These samples should be representative of the front, middle and rear portions of

the batch. Some states use samples from first and last quarters. Indiana recommends that samples be taken in accordance with the provisions set out in AASHO specification T 141 (23). However, where job conditions do not permit this, or where test data are needed prior to concrete placement, Indiana permits test samples to be taken from one portion of the load. When samples fail to meet the required slump, a rare occurrence with the present central-mixers, the mixing time can be adjusted or other appropriate corrections can be made.

Hauling the Concrete

Trucks have been the equipment most frequently used for hauling mixed concrete from plant to paver. The types in use include rear dump, side dump and tilt drum trucks. A recent development is the truck-mounted mixer which carries 7-1/2 cu yd and is capable of discharging in less than 60 sec. These trucks are designed to handle low slump paving concrete of the types used in slipform paving (14).

An uninterrupted supply of concrete is essential to the success of a slipform paving operation. Factors which cause delays in truck operation include delays in plant operation, long hauling distances, (such as where specifications do not permit hauling over prepared subgrade or subbase), inadequate supply of trucks, maintenance problems, etc. Contractors, in responding to a Roads and Streets questionnaire, indicated that a "good" efficiency for plant-to-paver truck hauling of

concrete could involve total truck-delay times ranging from 10- to 30-mins per paving day (24). Tight truck scheduling is essential to a successful slipform paving. Some contractors, in order to reduce delays, maintain one or two standby trucks for emergency use. Short wave radios can also be used to coordinate the trucking operations and the arrivals at the mixing plant. Contractors may either own their truck fleets or procure trucks through a subcontractor. In either case, good maintenance practices are highly desirable.

Some states do not allow concrete hauling units to move over the prepared subgrade during construction operation. This prohibition is understandable if the base is not stabilized, but as has been pointed out earlier, a stabilized base is essential to the successful operation of a slipform paver. Excessively long hauls to avoid a prepared subgrade may be both impractical and uneconomical. It will be beneficial to the state and to the taxpayer if design engineers will work in cooperation with contractors to determine the best and most economical routing of hauling units. A study is now underway by the American Concrete Paving Association (ACPA) to determine the weight restrictions which should be imposed in hauling over various types of completed bases (25). At present, the State of Indiana does not permit the use of the subgrade by the contractor's hauling units.

The number of hauling units that will theoretically produce the lowest cost on a paving project is related to the batch size, the truck capacities, the charges for labor and equipment, the batch cycle time, and the hauling time from the mixing plant to the point of use. The minimum required number of hauling units and the corresponding cost per cu yd of concrete can be readily calculated if the batch size is some integral multiple of the truck capacity (10).

For example:

Assuming a hauling speed of 30 mph, and allowing 2 mins on each trip for delays while loading and unloading, the elapsed time for a round trip of a haul unit to a point L miles from plant can be expressed in seconds as

$$t = t_f + \frac{7200 L}{v}$$

t_f = delay time for loading and unloading, seconds

v = average speed, mph

For a minimum time C secs between batches, the number of units D corresponding to a realistic 80% system efficiency (E) is

$$\begin{aligned} D &= E \frac{t}{C} = \frac{E}{C} t_f + \frac{7200 E L}{C v} \\ &= \frac{96}{C} (2L + 1) \end{aligned}$$

With a given equipment system, the principal equipment variable affecting cost is the

number of haul units. This number should not exceed D. In order to realize the lowest production cost, the haul unit capacity is a multiple of the mixer batch.

$$\text{Cost/cu yd} = \frac{K + D_1 X}{P}$$

where K is the sum of delay costs of plant equipment and labor; paving equipment and labor; and items such as road maintenance, project office, management, etc.; D_1 = actual number of haul units used; X = daily cost of one haul unit with driver; P = average daily production in cu yd.

Delivery of Concrete to Paver

The plant mixed concrete is hauled in trucks to the job site. Here, depending on the method of construction, it is either deposited into a receiving hopper or placed directly on the subgrade. The concrete is deposited into the hopper of a belt placer or of a slipform paver, depending on the train of equipment and the method of construction. In many instances, the subbase is moistened before the concrete is deposited.

Rate of Supply

A controlled supply rate for the concrete is of major importance. Repeated stopping and starting of the paver will affect the smoothness of the pavement, and the most

satisfactory results will be obtained when the paver is maintained at a uniform speed. This will require a uniform cycle of truck hauling and delivery, which is difficult to attain. When the delivery cycle becomes irregular, it is best to slow the paver down to a creep during a break in the truck cycle rather than to stop it completely.

Besides controlling the dump rate of trucks, dump men must space the truck loads uniformly across the width of the paver. This is essential when paving 3- or 4-lanes at a time, as is currently practiced in California. An unbalanced load on the paver may cause loss of traction in any of the tracks and the net result is an excessively rough pavement (20). The State of Ohio experienced this difficulty in its early slipform paving operation. Here the machines were unequally loaded to the extent that they rode over the concrete, thereby producing choppy surfaces. The problem was attributed to the type of machine used, but this conclusion was of questionable validity.

The supply of concrete, as well as its rate of delivery, can limit the slipforming operation. This was the case when Matich paved his 12,413 ft of concrete pavement and Barton paved his 13,240 ft all in one working day. In each of these cases, operations had to be discontinued because concrete could no longer be supplied (11,24). The slipform manufacturers claim that higher paving production rates can be realized if an adequate supply of concrete can be produced and delivered to the paver. In the future, if concrete can be

supplied fast enough, paving 20,000 ft in a working day may become as common place as paving a mile a day is now.

Distribution of Concrete

As mentioned earlier, concrete can be dumped into the hopper of either a slipform paver or a placer, depending on the method of construction and the type of equipment being used. Some slipform pavers, such as Guntert and Zimmerman's, have integral spreaders and the concrete is merely dumped into their receiving hoppers (Figure 7) or on the subgrade (Figure 8). The slipform then spreads, consolidates, and forms the slab. However, when reinforcing steel has to be incorporated into the slab, it is customary to use one or two spreader-placers. These either spread the concrete before the reinforcing steel is placed, or spread the concrete around reinforcing steel which is already in place. The slipform paver then consolidates the concrete and forms the slab. When the contractor is using the "sandwiching" technique by placing the steel between two layers of concrete, he usually needs two spreaders. The first spreader lays the concrete to a certain depth and the reinforcing steel is placed on this layer. The second spreader then lays the second layer of concrete to bring the pavement to its full depth. This second spreader will be followed by the slipform paver. In other methods of steel installation, only one spreader is required. Concrete spreaders are guided by string wires or line and paving depths are

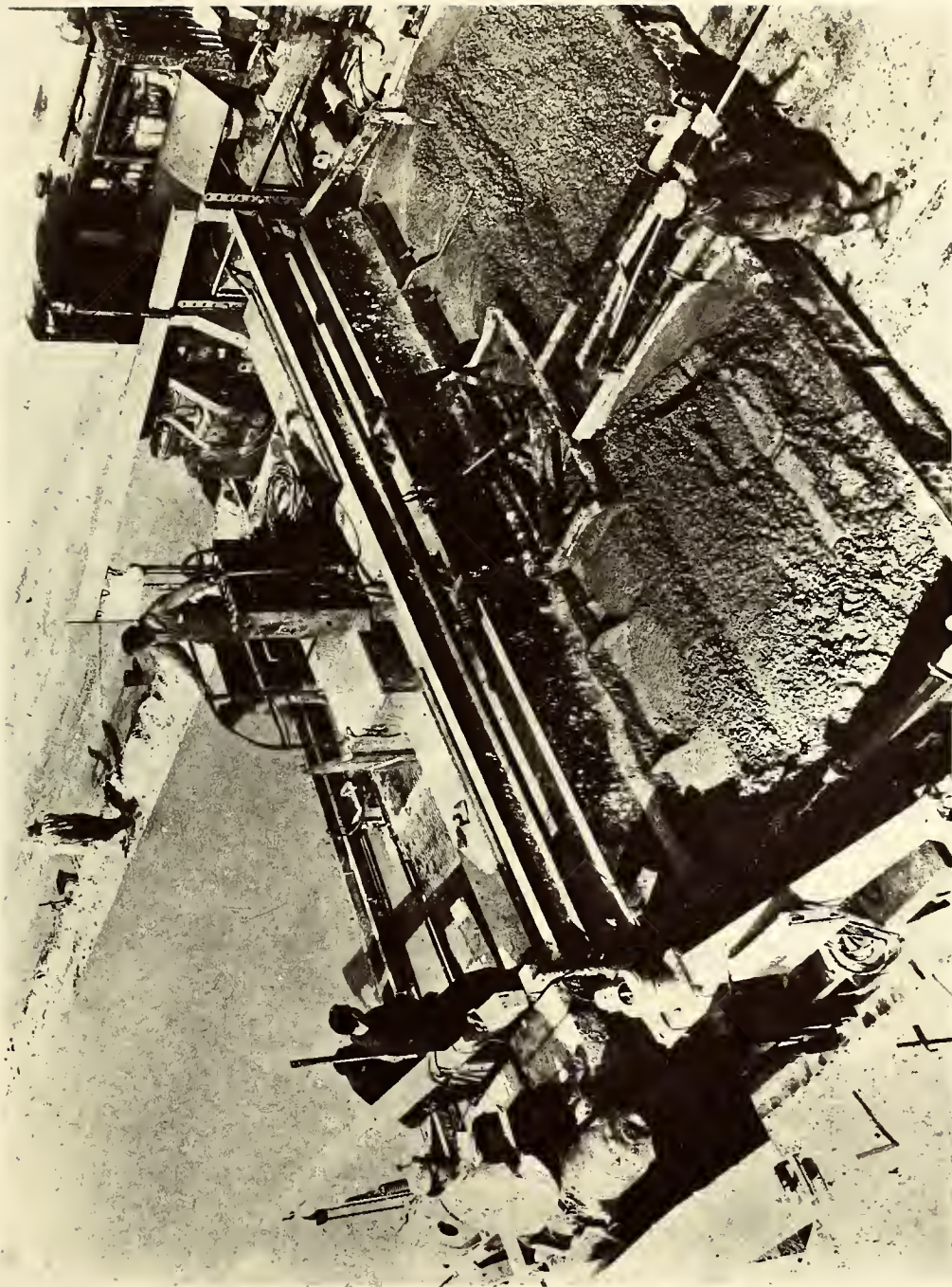


Figure 7

Concrete is Dumped by Truck into the Hopper of Slipform Paver

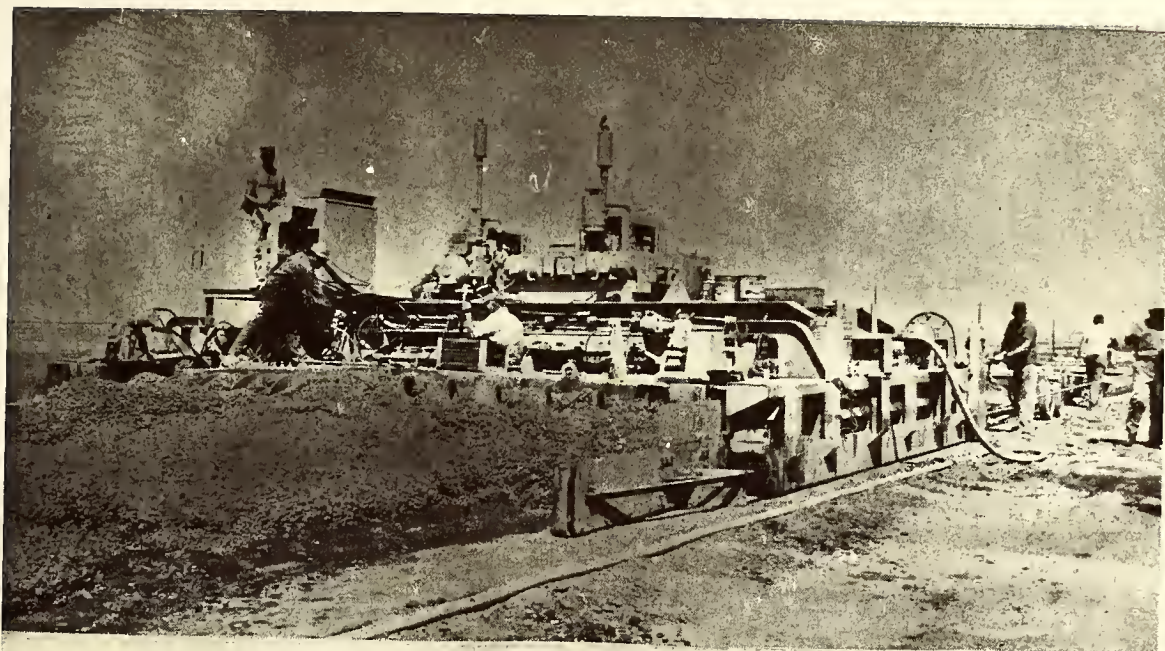


Figure 8

Concrete is Dumped by Truck Directly onto the Subbase

automatically controlled. Several types of spreaders are in production, one of which is shown in Figure 9.

Formation of the Slab

Slab formation is perhaps the most difficult part of the construction operation. First, before the 1- to 2-inches slump concrete can be consolidated and finished, it must be distributed across the paving width by augers. These augers may be small and short, designed to move across the width of the pavement as in Gomaco's slipform paver. Alternatively, a giant auger may bridge the front of the paver, as on the Rex and CMI slipform pavers. Regardless of its type, an auger in front of a slipform paver is rarely operated when a belt placer is used with the paver. The placer is capable of spreading the concrete to the desired grade, and the paver need only perform localized levelling.

The major slab forming devices in most slipform pavers include the auger which distributes the concrete; a metering device which measures the quantity of concrete passing under the paver and strikes off the excess concrete; a consolidation mechanism which consists of internal and surface vibrators spanning the width of the pavement; a slab forming device (referred to by such names as "forming plate", "extrusion finisher" or "extrusion pan", depending on the manufacturer) which extrudes the concrete in the form of the pavement slab; and a float pan which gives the pavement an initial finish. There are several slight differences

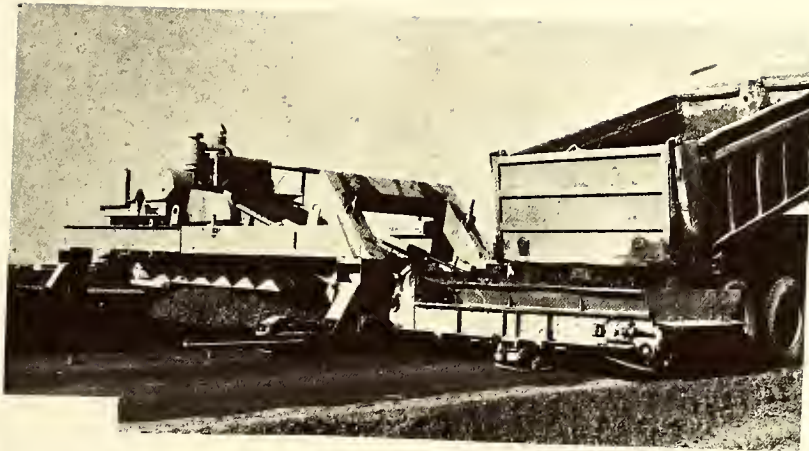


Figure 9

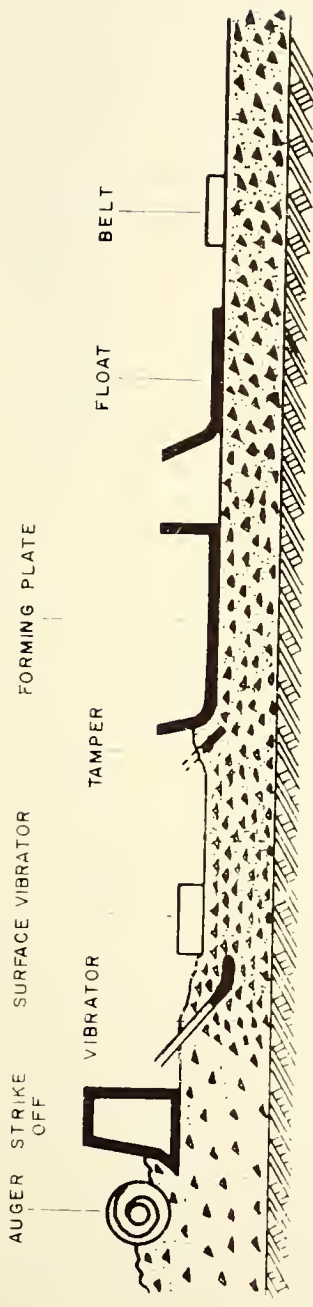
Rex's Belt Placer

(Notice the protruding hopper)

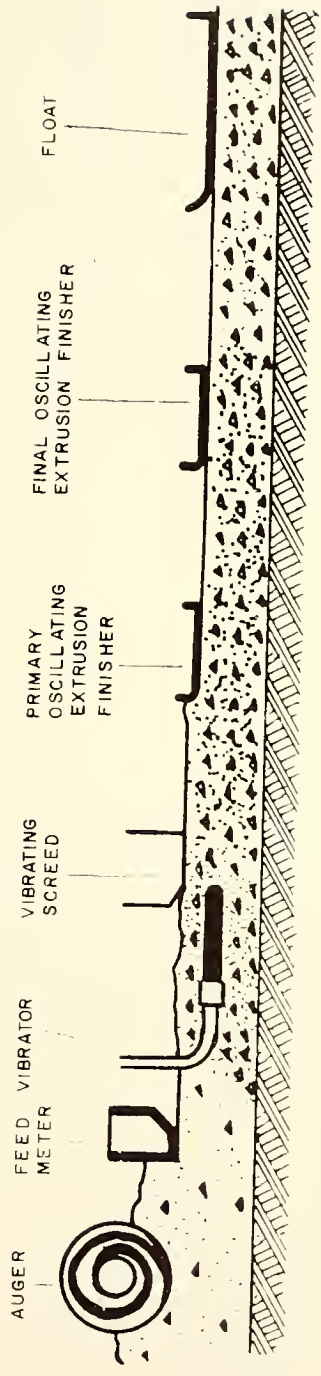
between machines, depending on the make. In some, the consolidation mechanism consists of a tamper in front of the forming plate. Others contain two oscillating extrusion finishers and pan floats. Instead of trailing forms, some machines have built-in edge formers. Figures 10 and 11 show the major components of the pavers from three leading manufacturers.

Internal Vibration

The purposes of internal vibration are two in number. The first is to consolidate and compact the plastic concrete; the second is to regulate the amount of surge behind the conforming screed, and thus overcome surface tearing under the screed. Despite general agreement as to these purposes, and despite the efforts of vibration equipment manufacturers, "nobody seems to understand vibration" (25). In fact, the vibration of concrete during slipforming has developed into a critical problem. Iowa has banned the use of spud vibrators until further studies can be made, and Indiana will not allow the use of vibration equipment to place reinforcing steel for slipforming continuously reinforced concrete pavements. The general indecision and lack of knowledge in this area are evidenced by the ambiguities to be found in the vibration specifications of several states. Some require a minimum frequency of 7000 vpm for internal vibrators while others specify the same frequency as the maximum permitted (26). Some states specify the use of



REX PAVER



CMI PAVER

Figure 10

Schematic Diagrams of Paver Functions of a Rex Paver and a CMI Paver

NOTE

STANDARD SLIDING GATE HEIGHT IS 23" OFF OF GRADE. CHECK TRUCK TAIL GATE HEIGHT FOR CLEARANCE. SPECIFY GATE HEIGHT IF OTHER THAN STANDARD.

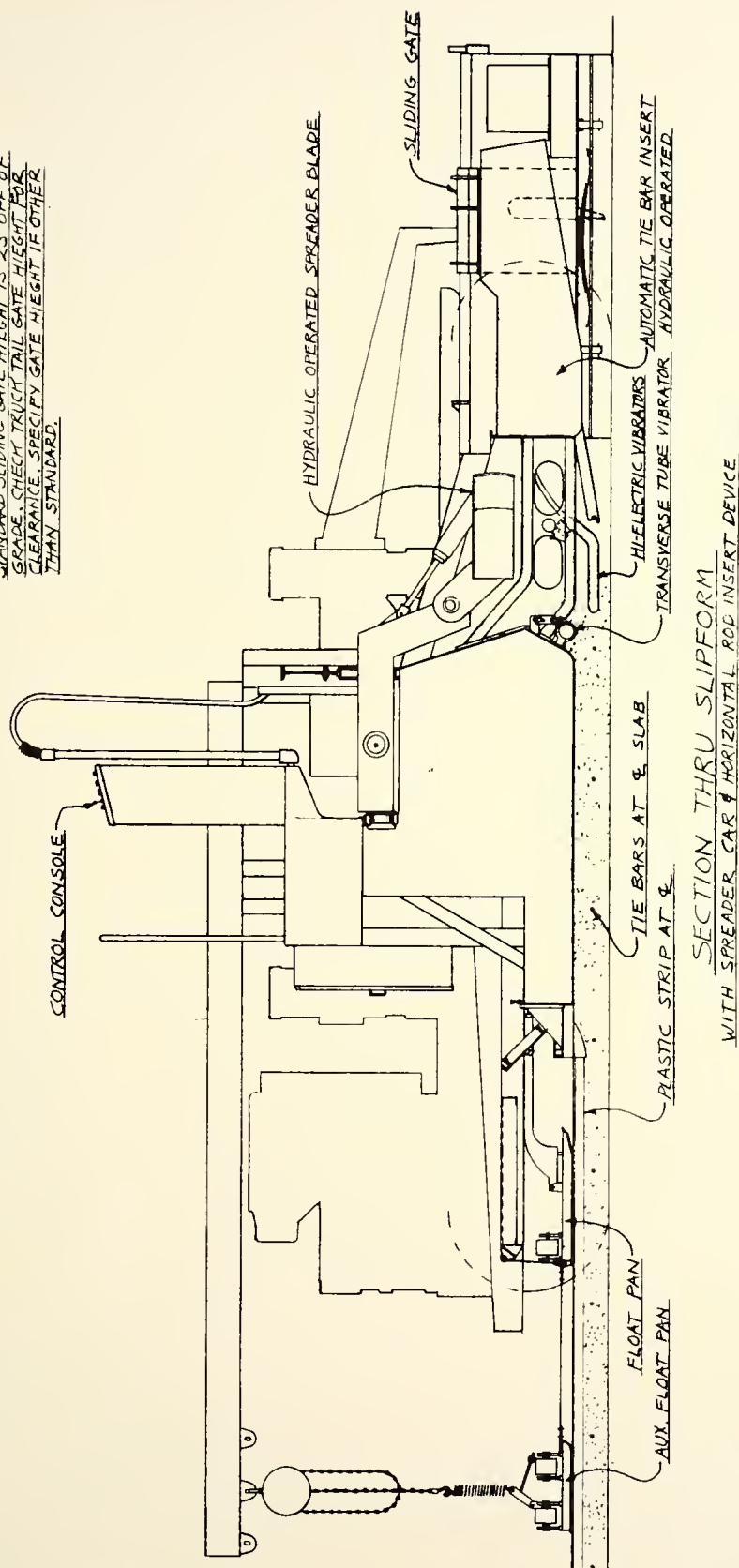


Figure 11

Section Through a Guntert and Zimmerman Slipform Paver

(Notice the built-in spreader and two pan-floats)

two types of vibrators (27), while others are satisfied with one type.

Many factors influence the proper vibration of a slip-formed pavement. These include the maximum size of aggregate; the sand content and the slump of the concrete; the temperature of placement; the size, shape, and weight of the vibrator; the number of cycles of vibration per second, and the space between the vibrators; the rate of motion of the slipform paver; and the experience of the paver operator. Field problems which arise from the factors just mentioned include segregation of the concrete, as characterized by the absence of coarse aggregate in the top inch of the slab; serious reductions in air content; subgrade intrusion; settlement of reinforcing steel; and surface depressions at laps of reinforcement and at doweled joints (21).

Laboratory studies have been conducted in California to determine the minimum amplitude and frequency necessary to compact concrete adequately. These studies showed that acceptable compaction could be obtained under laboratory conditions with a frequency of 5,000 vpm and an amplitude just sufficient to be perceptible on the surface of the concrete at a minimum distance of 1-ft from the vibrating element. Spud type vibrators spaced at 30-in on centers and placed at a distance of about the thickness of the slab ahead of the conforming screed satisfied these minima. It was also found that positioning the vibrators too close to

the screed resulted in an uncontrollable surge behind the screed, while positioning them too far ahead of the screed resulted in excessive load on the paver and tearing on the surface of the slab (20). Other states have also made efforts to find the combination of amplitude and frequency which will give the best vibration results. These efforts have included the use of vibrators spaced at 24-in and 18-in; 1- to 1-3/4-in slump concrete; vibration frequencies approaching 10,000 cps; and combinations of several sizes and weights of vibrators. None of these investigations, as far as is known, has provided a complete answer. A committee of the ACPA is studying this problem now, as is the Dart Division of Koehring Company (26).

It would be helpful if the slipform operator could judge, by the quantity of grout on the surface of the slab or by some other means, whether or not he is getting proper consolidation. The problem of subgrade intrusion clearly indicates that the vibrators may be either touching the subgrade or else are very close to it. This can be corrected by raising the vibrators. Excessive grout floatation and reinforcing steel settlement can be due to variations in concrete slump and consistency or to improper consolidation. In some instances an experienced operator can observe some of these variations and can take appropriate corrective actions.

Trailing Forms

A few years ago, the length of trailing form was a subject of much discussion. This concern was reflected in early specifications for slipform paving, in which up to 120 ft of trailing forms were specified by some states. It was believed that the pavement edge would slump away if it was not supported by forms for some minimum time, which was translated into a requirement for a minimum length of form. It was not realized at the time that the moving forms had a polishing effect on the pavement. This, in itself, could result in excessive slump, the very situation that the length of form was supposed to prevent. If the concrete is properly consolidated, with well-formed edges, it has been found that the length of forms need only be that required to support the edges of the pavement under the paver. On this basis, equipment manufacturers judge that a trailing form with a length of between 18- and 32-ft should be sufficient for the normal slump of concrete used for slipform paving. On the jobs underway in Iowa, North Dakota and Minnesota during the summer of 1970, trailing forms only 30 ft in length were used. However, some states still prefer to use 36- to 48-ft lengths of forms (Figure 12).

The manufacturers of machines which are still equipped with trailing forms claim that the forms are useful in providing a working area for the finishers who repair tears and other imperfections on the surface of the finished

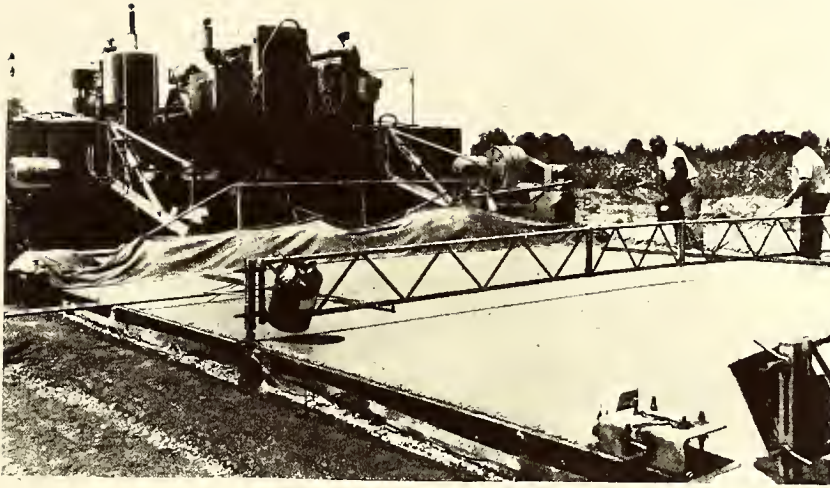


Figure 12

Paver Carrying Two 16 ft. Sections of Trailing Forms
(Notice the straight edge on the slab at extreme left
and the man at extreme right holding another one)

pavement. Many of the slipformers now available do not use trailing forms, but the slabs they lay will still be finished with straight edges. The men who are performing the finishing on these slabs must take some precautions so as not to break the pavement edges. One contractor-built paver which was observed in Iowa during the summer of 1970 used no trailing forms; however, the pavement had some noticeable side slump. This defect was not attributed to the paver itself, but instead was considered to be due to high concrete slump.

Slab Thickness Measurement

The accuracy of the thickness of the slipformed pavement depends, to an appreciable extent, on the accuracy of the subbase. The slipform paver extrudes the consolidated and compacted concrete between the limits defined by the forming plates, the side forms and the prepared subbase.

Current Method

There are several methods in current use for checking the thickness of the slab. These include stabbing, coring, and measuring from a pregraded taut wire to the slab surface. The technique of stabbing involves carefully inserting a calibrated steel rod into the pavement almost immediately behind the paver. The rod, about 1/4 in. in diameter and calibrated to read the proper depth, is inserted until its end touches a metal plate which has previously been laid on the subgrade. This technique is not very accurate, but gross errors can be quickly detected by it.

A coring device can be used to obtain a sample of about 4 in diameter at intervals of about 1,000 ft. The core diameter and the coring interval may be varied, depending on the requirements of individual states. If the core depth is not within the allowable tolerance, another core, about 2 in in diameter, is cut in the same vicinity. This second core establishes whether or not the discrepancy observed in the first core was unique to its position. The coring method will give the actual thickness of the slab at the location where the core is taken, but any generalization made with respect to the total slab is questionable. Another disadvantage of coring is the fact that it is a destructive method of testing.

The third method is more accurate than the first two. It involves using a string stretched taut between two graded points on both sides of the slab. The subgrade elevations have been previously determined at these points, so that slab depths can be measured with precision. The string is stretched taut and a job inspector measures the distance from the string down to the slab surface from one side to the other. The thickness of the slab is obtained by simple arithmetic.

Figure 13 shows two of the three techniques just described. Other measurement techniques are probably in use, but none has gained the approval of the paving contractor. Statements such as "We'd like equipment that will

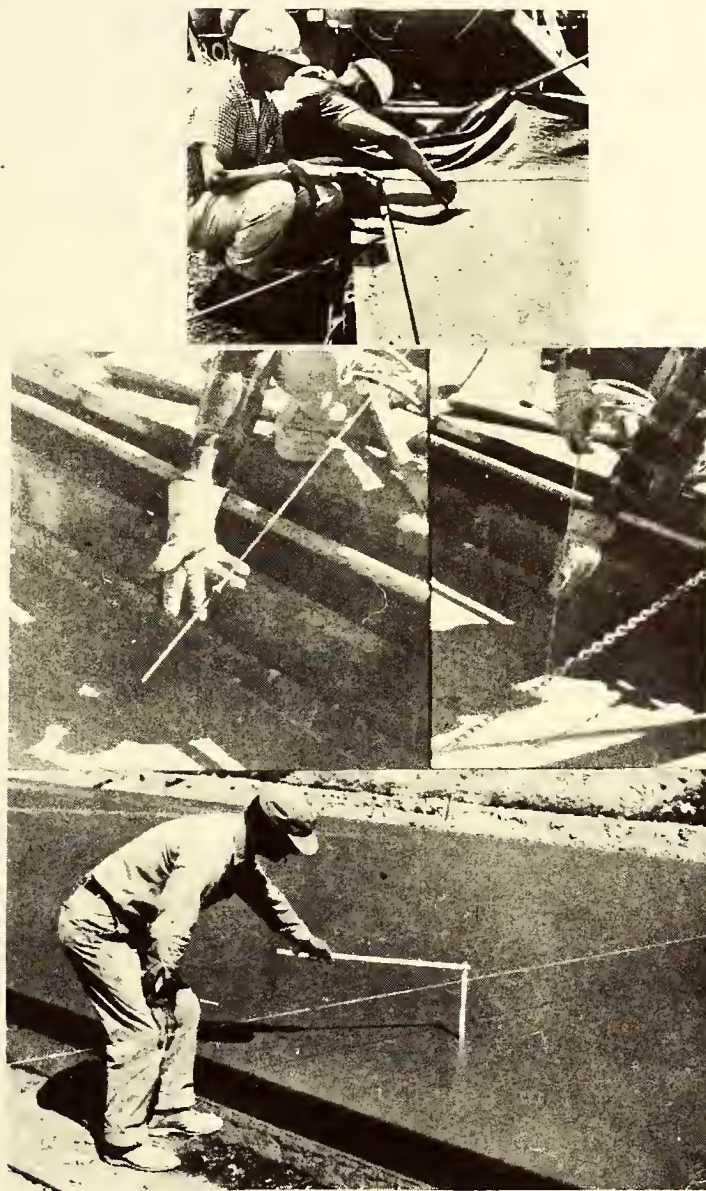


Figure 13

Methods of Checking Slab Thickness

check pavement depth on the move..." (21), attest to this dissatisfaction. In fact, all of the methods just described are merely a means to an end. They speak for a particular area or position, but not for the entire slab length and width. Besides this, the techniques are too slow. In some, the paver has to stop completely before and during the period of the test. In other instances, the test is made after the paving operation has been completed and the contractor can do very little about his "error". There is a need for a depth-measurement device, built into the paver's control panel, which can scan depths across the pavement width and adjust the forming plates accordingly to ensure uniform depth. Until the equivalent of such a device is available, it will be necessary to continue with the slow and inaccurate methods which are presently in use.

Prospective Methods

Rapid and non-destructive methods of measuring pavement thickness, both during and after construction, would have many advantages over the current methods of taking cores or stabbing plastic concrete. They will permit a much larger number of thickness measurements per lane mile, and therefore provide a more accurate basis for the determination of compliance with specifications. They will also make it possible to rely on statistical sampling procedures for product acceptance. Measurements during construction will permit the contractor to alter paving operations to meet specified tolerances.

Despite much speculation and experimentation, no instruments have been developed which can measure the thickness of a pavement slab accurately and reliably by non-destructive means. Techniques for such measurements are largely in the experimental stage and include the use of ultrasonic pulses, earth resistivity, mechanical impulses with ultramicrometer detectors, and spreading of radioactive pellets prior to laying the pavement. Models have been built which have been able to measure thicknesses to within $\pm 2\%$. Extensive work in this area has been undertaken at the Illinois Institute of Technology (28) and at Ohio State University (29). Both of these schools have constructed experimental devices and tested them on existing pavement.

The Sonic Devices make use of large diameter transducers, short mechanical impulse sources with ultra micro-meter detectors, and high frequency receivers. The first technique involves sending out an ultrasonic pulse and measuring the time it takes to travel down through the pavement and back. A model of this instrument was built at Illinois Institute of Technology (IIT) and a full scale version was built and tested at Ohio State University (OSU). See Figures 14 and 15. The IIT equipment can be operated by an unskilled operator, whereas the OSU equipment requires a semi-skilled operator. The technique can be used with hardened or plastic concrete pavement and with bituminous pavement.

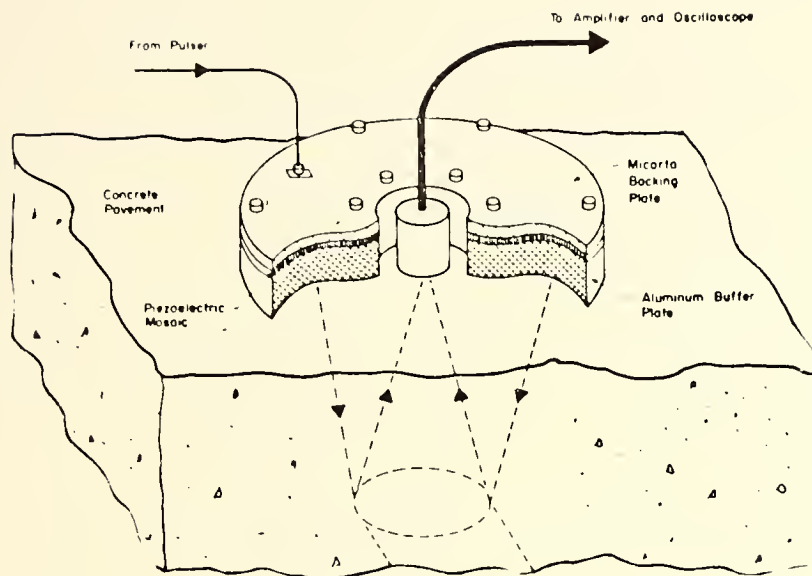


Figure 14

Functional Drawing of Ohio State University's
Pavement Thickness Gauge

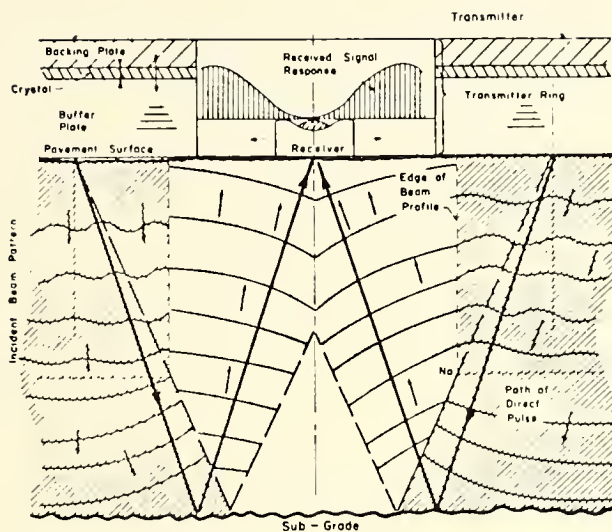


Figure 15

Schematic Drawing of the Sound Field in the Vicinity
of the Ohio State University's Pavement Thickness Gauge

The second sonic technique involves the production of short pulses by mechanical impact and the use of an ultramicro-meter detector for time-of-flight pulse separation. This instrument requires a semi-skilled operator to adjust the ultramicro-meter correctly. The problems associated with this method include its inapplicability to plastic concrete and its vulnerability to false or stray signals.

The Nuclear Technique involves the laying of radio-active pellets on the subgrade before the concrete is placed. The method is simple and the measuring apparatus can be handled by an unskilled man. The preparation cost is about \$80 for a strip of pavement 15 ft wide and one mile long, and the method is applicable to both plastic and hardened concrete. The researchers believe that this is the best equipment for depth measurements on new pavements. However, it cannot be applied to existing roads, nor can it be used to obtain continuous measurements of thickness.

The Earth Resistivity Technique has been described by Mr. R. W. Moore of the Bureau of Public Roads (30). It involves the use of four electrodes equally spaced in a line on the surface of the pavement. The resistance to the passage of an electric current through the pavement is then measured. The method is based on the premise that a concrete pavement usually has a resistivity characteristic different from that of the underlying soil or base layers. It has been speculated that the method might be used to locate the

position of reinforcing steel in the slab. More research is needed to fully identify the potential of this technique.

In reviewing the experimental methods of thickness measurement which have been developed thus far, it appears that the need for accurate and non-destructive methods of measuring pavement thickness has not been satisfied, although the prospects are good. All of the methods just described require from 30 seconds to a few minutes to check pavement thickness to within $\pm 2\%$ (in the case of the nuclear pellets technique, to within $\pm 1\%$). Nevertheless, it is believed that a simple, inexpensive and accurate device will ultimately be perfected, be it sonic, nuclear, or electrical.

Finishing the Slab

In theory, a slipformed pavement should be so perfectly built that it will require no hand finishing. To achieve such a standard, several ideal conditions would have to be met. These include a perfectly graded subgrade, an ideal concrete slump, a uniform rate of concrete charging which permits the paver to advance continuously at a uniform speed, and other equally impossible requirements. In actual practice, additional working of the concrete surface is needed to fill in tears and other imperfections. This is done with the aid of either long handled floats or a self propelled tube finisher.

Using the first method, two or four finishers work on both sides of the pavement immediately behind the paver.

Each worker drags a long handled float across the pavement (see Figure 16) to fill in any low areas or surface tears. The second method employs a self propelled cart to carry two 4- or 8-in diameter aluminum or steel pipes, which are positioned diagonally across the pavement. The reciprocating action of the tubes develops a small amount of grout to eliminate minor imperfections and produce a uniform surface appearance (2,20), see Figure 17.

As in side form paving, a slipformed pavement requires surface texturing to improve its skid resistance, prevent hydroplaning and sometimes to improve slab drainage characteristics. Texturing of plastic concrete is done by fiber drag such as burlap, belt, carpet, etc., or by brooming.

Fiber Drag

Burlap is the most extensively used form of fiber for surface texturing of plastic slipformed pavement. See Figure 18. Other forms of fiber that have been used include nylon ropes, mops, household carpets and belts. Most of these have proved satisfactory (31). The dragging operation is done mechanically by the slipform paver or by the tube float machine, or it may be performed manually.

There are other machines available that can be used to burlap or belt. The belt usually consists of two-ply rubberized canvas. It is mounted on a frame which is reciprocated through an eccentric action. The power for this reciprocating movement is provided by the engine through a

the batch. Some states use samples from first and last quarters. Indiana recommends that samples be taken in accordance with the provisions set out in AASHO specification T 141 (23). However, where job conditions do not permit this, or where test data are needed prior to concrete placement, Indiana permits test samples to be taken from one portion of the load. When samples fail to meet the required slump, a rare occurrence with the present central-mixers, the mixing time can be adjusted or other appropriate corrections can be made.

Hauling the Concrete

Trucks have been the equipment most frequently used for hauling mixed concrete from plant to paver. The types in use include rear dump, side dump and tilt drum trucks. A recent development is the truck-mounted mixer which carries 7-1/2 cu yd and is capable of discharging in less than 60 sec. These trucks are designed to handle low slump paving concrete of the types used in slipform paving (14).

An uninterrupted supply of concrete is essential to the success of a slipform paving operation. Factors which cause delays in truck operation include delays in plant operation, long hauling distances, (such as where specifications do not permit hauling over prepared subgrade or subbase), inadequate supply of trucks, maintenance problems, etc. Contractors, in responding to a Roads and Streets questionnaire, indicated that a "good" efficiency for plant-to-paver truck hauling of

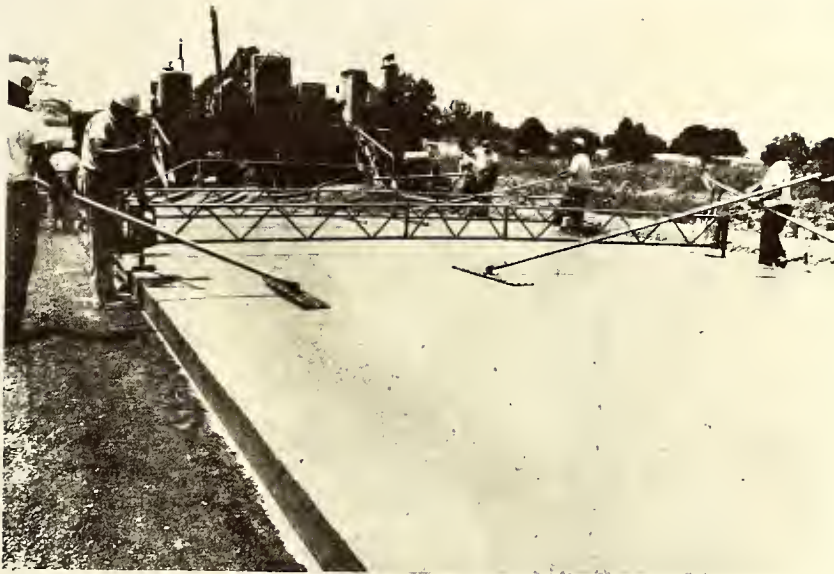


Figure 16

Finishers Using Long-Handled Floats for Final Slab Finishing

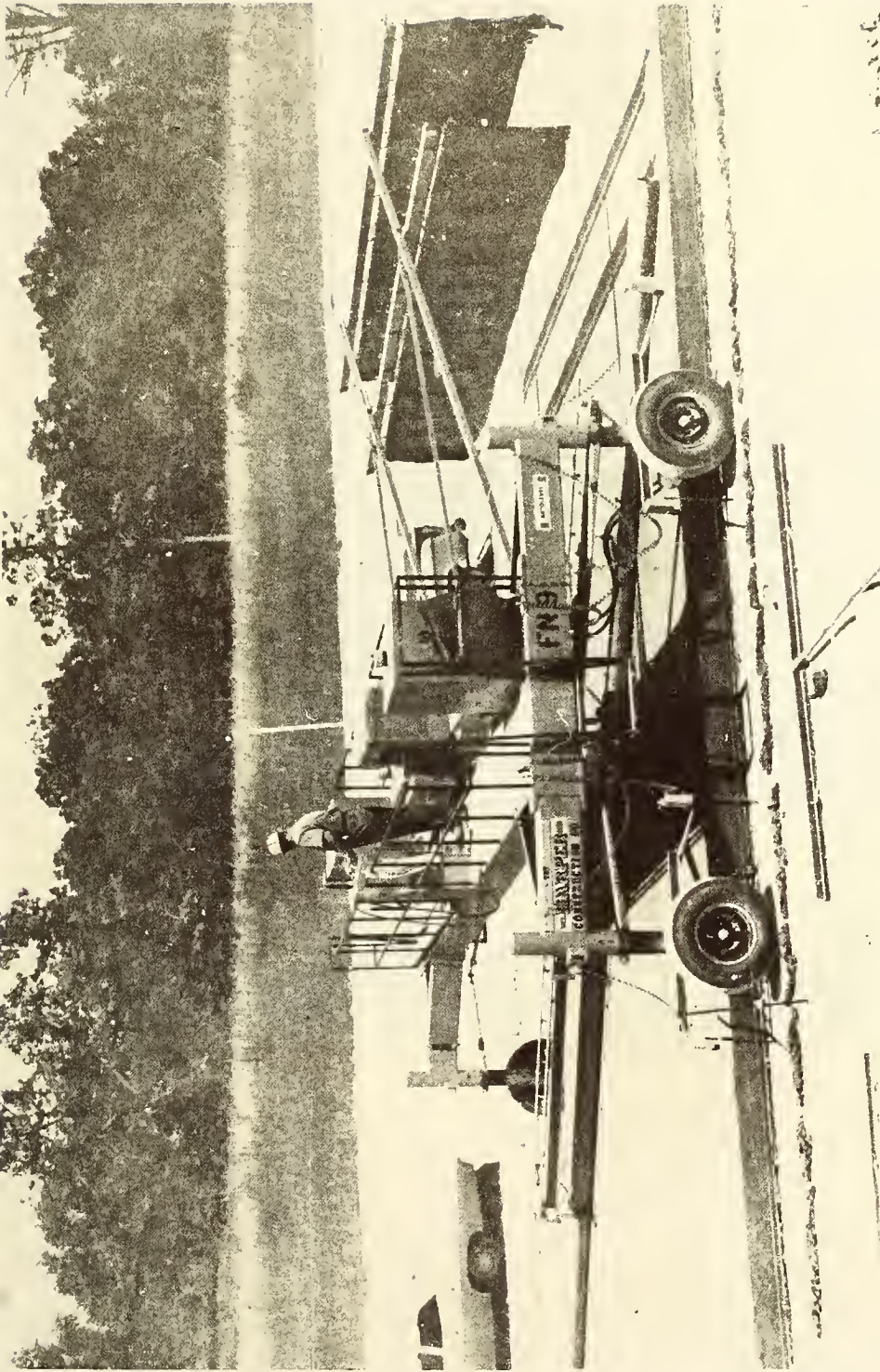


Figure 17

Tube Float Finisher with Burlap Mat in Raised Position

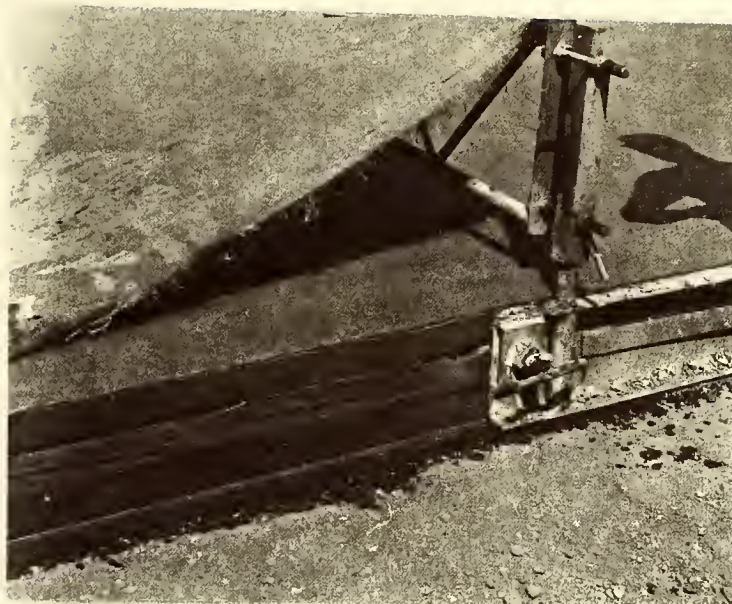


Figure 18

Coarse Textured Burlap,
Attached to the Trailing Form of a Slipform Machine

drive arm, and the belt can be raised or lowered. The machine can be used with side forms or with a slipform machine.

The use of burlap or belt is not specifically stated in the Indiana State Highway Specification. A contractor will have to ask for permission to use either. Figure 18 shows a burlap operation on I-465 near Indianapolis. The consensus of the contractors interviewed in the course of this study is that burlap dragging is the best for surface texturing. This conclusion is supported by the data supplied in Table 1, which were obtained from an experiment conducted in Ohio (31).

Brooming

Another technique for striating the surface of a plastic pavement is by longitudinal or transverse brooming. This may be done by an attachment to a spray curing machine; or by a special texturing machine; or it may be performed manually. When the brooming machine is an attachment to a spray curing machine, it can take either of two forms. A series of individual brooms can be mounted on a bridge, with the capability of texturing in both longitudinal and transverse directions; or a long broom capable of imparting only transverse texture can be similarly mounted, Figure 19. The equipment manufactured by the Barton Corporation of Towanda, Illinois, can burlap, groove, and broom in both the transverse and longitudinal directions. Nylon and fiber brooms can be used for texturing plastic concrete, and metal combs can be used for grooving hardened concrete.

Table 1. Pavement Texturing Depths as Related to Texturing Methods*

| Method of Texture | Number of Tests | Depth Range, in. | Average Depth, inc. |
|--|-----------------|------------------|---------------------|
| Burlap Drap (Long.) | 6 | 0.023-0.032 | 0.028 |
| Rug-Backing (Long.) | 5 | 0.016-0.026 | 0.021 |
| Longitudinal Broom (Light) | 10 | 0.015-0.023 | 0.019 |
| Longitudinal Broom (Heavy) | 6 | 0.023-0.026 | 0.024 |
| Transverse Broom | 6 | 0.016-0.023 | 0.017 |
| Transverse Groove - Longitudinal Broom | 6 | 0.032-0.046 | 0.037 |

* Depths based on sand patch test.

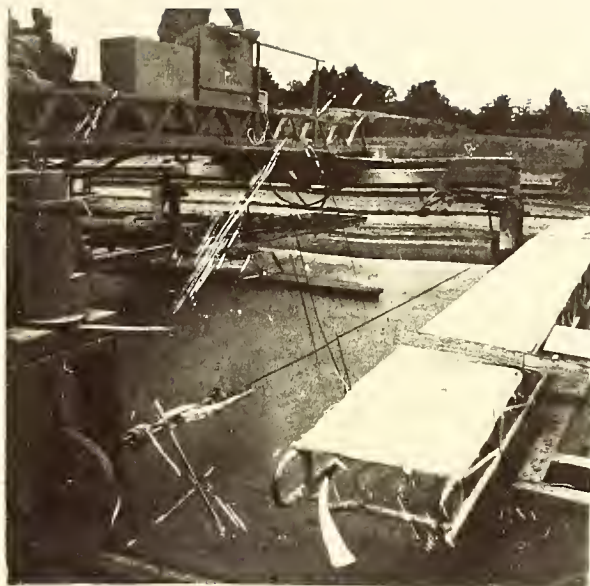


Figure 19

Figure 19. Bridge, Machine Used on I-69 Near J. 1971

Brooming should be done as soon as possible after finishing. This will prevent the build-up of balls of mortar in front of the brooms. In addition, the texture produced from brooming a set concrete is shallower than would be the case if the concrete were still plastic (26).

Indiana requires final pavement finishing by brooming "unless otherwise specified or directed" (23). Mr. Gene Hallock, Assistant Chief Engineer of the Indiana State Highway Commission, has expressed the belief that the state is not getting good broom finishes. Contractors in informal interviews on this subject, have suggested that the reason for this may be the state's failure to specify the required texture of finish i.e. whether coarse or fine brooms. In practice, this means that the contractor will use fine brooms if the state official who inspects the job likes a fine texture, and will use coarse brooms if the inspector likes a coarse texture.

Ohio's Experiments

A few summers ago, the Ohio State Highway Department conducted an informal experiment in which many state contractors took part. Its purpose was to obtain deeper and more effective surface textures on concrete pavements. The state felt that deeper and more uniform textures would alleviate the slippery conditions that were found to develop after a few years (31).

The contractors, after having been informed of the problem, were encouraged to experiment with various

techniques. One experimental method used brooms mounted on a bridge to impart longitudinal texture in the plastic pavement. This texture was overlaid on a pavement which had initially been dragged with burlap, and the results were very satisfactory. Another method, which also proved satisfactory, used the underside of a household carpet. However, the "best and most uniform texture" was obtained by successive passes with multiple layers of burlap over the pavement surface (31). One burlap drag was hung on a traveling bridge following straight edge operations, another was hung at the rear of a combination float finisher, and the last was mounted on a self-propelled machine which was capable of fast travel in both forward and reverse directions. Four thickness of burlap were used and the self-propelled machine made three or four passes. The result from this operation was also satisfactory.

Another experiment used the Barton machine, described earlier, to texture pavements longitudinally and transversely with brooms. This was in addition to a combination of transverse grooves and longitudinal burlap. The experiment showed that transverse brooming gave a higher skid number than longitudinal brooming. However, transverse brooming had the undesirable feature of producing a higher level of traffic noise. (Indiana uses transverse brooming). The experiment was performed with fine brooms. Mr. Dixon of Ohio Department of Highways, in a conversation with the writer, expressed the opinion that a coarser broom would

have imparted a coarser texture and thereby produced a higher skid number and a better and more durable finish. No subsequent experiment has been conducted to prove or disprove this statement.

From these series of experiments, Ohio State now requires that striations produced on a finished pavement be approximately 1/16" in depth. The method of achieving this is not specified (31).

Longitudinal Versus Transverse Texture

Whenever discussions on texturing arise, they most often center on the relative merit of longitudinal versus transverse texturing. Each method has its own advantage, and there are many reasons why some states prefer one to another. Depending on the technique used, Indiana permits either transverse or longitudinal textures; transverse if obtained by brooming, and longitudinal if obtained by burlap dragging.

Longitudinal texture, when effectively applied, tends to overcome hydroplaning. It also encourages vehicles to track and remain in their direction of travel, even when skidding. This property is desirable on high speed interstate highways where good traction is needed and where there is seldom any need for panic stops.

Transverse texture, on the other hand, has a higher skid resistance and channels water away from the pavement more quickly than does longitudinal texture. It therefore

minimizes hydro planing. Transverse texture has a higher noise level than longitudinal texture, although not to an objectionable extent. It also tends to reduce the speed of a slowing vehicle more quickly than will longitudinal texture. It can therefore be effectively used at termini of ramps, at intersections where vehicles must come to a stop, and in areas where traffic must reduce speed in preparation for directional changes (31).

In summary, it appears that longitudinal texture is good on interstate highways where the traffic moves at a high speed and does not have to make sudden stops, but it has a relatively low skid resistance. Transverse texture, on the other hand, is good where the traffic has to travel slowly or come to a full stop. Further research is necessary to fully determine how these two techniques affect the vehicle control under various weather conditions and at several speeds of travel.

Curing the Slab

The newly completed pavement is cured in several ways including white membrane, ponding, weatherproof blankets, straw, cotton mats, double burlap, polyethylene sheets, kerosine, and water mixed with linseed oil. The State of Indiana may specify the use of any of these methods, excluding the last two. The techniques which involve the use of fluids are usually executed with rubber tired equipment, using pressure sprayers to distribute the fluid across the

width of the pavement. Many contractors dislike the use of burlap and polyethylene fibers because a lot of time is spent in placing these sheets and in picking them up again. Also, when burlap is used, it has to be kept wet for between three to four days. For these reasons, contractors will frequently elect to use the spray curing machine whenever the specifications allow it.

Checking the Surface Smoothness

The surface smoothness of the finished pavement is checked so that it can be compared with the specified tolerances. This also provides a useful check on the quality of the entire paving operation.

In the last 50 years, several devices have been developed for locating, measuring, and evaluating the high and low spots on a pavement surface. These devices have been identified by such names as roughometer, roadometer, profilometer, road roughness indicator, high-low detectors, etc. All of these devices attempt to measure the surface contours of the pavement surface, recording these readings for subsequent study and analysis. In general, the equipment now available has only limited accuracy. The slower equipment is usually more accurate, but even units of this type do not produce consistent readings of surface roughness. Such factors as length of operation and conditions of temperature and moisture content appear to influence the results (32,33).

The further drawbacks of many of the units now available

can be briefly summarized. The manually pushed devices are tiresome to use and do not always give accurate surface readings. Those towed by vehicles, even though fast, cannot be used until the pavement is hard enough to support vehicular traffic. Also, some of them put out their readings in forms not immediately usable. The person who suffers from all these delays and inaccuracies is the paving contractor. A dependable and accurate method which can check the smoothness as the pavement is being laid is badly needed. This would eliminate the delays and uncertainties which are inherent in the present devices.

Roughness measuring devices can be classified into the slow manually-pushed types and the faster automobile trailer types. The pushed types include Hi-Lo detectors or "straight edges", and California-Michigan-type profilographs. The trailer types include the Bureau of Public Roads' (BPR) roughometer and its modifications, General Motors Research (GMR) road profilometer and PCA road-meter. One device that does not fall into either category is the Kentucky accelerometer which is mounted on the passenger's chest.

Hi-Lo Detectors

These employ the principle of an ordinary straight edge which, when placed on an irregular surface, will indicate high and low points. Modifications to the straight edge include attaching wheels at either or both ends and a center wheel which rises and falls with the inequalities of the pavement surface. The motion of this center wheel actuates

a pointer or stylus and thus records vertical displacements on a strip of paper. Some recording devices have dye markers that indicate any section of the pavement which does not meet the specifications. The State of Indiana has a unit of this type which it uses on newly constructed pavements. The continuous drag of the straight edge across the surface is tiresome and annoying, especially over substantial lengths. The machine also exaggerates some "bumps" and minimizes others (34). Figure 20 shows a Soiltest-type Hi-Lo detector.

California Profilograph

The California profilograph, several variations of which are available in many states around the country, is a further modification of the regular straight edge principle. It is essentially a 25-ft long beam with a recording wheel at the mid-point and multiple support wheels at the ends. The floating center wheel records a scale profile of the pavement surface by means of a linkage device (35). Figures 21 and 22 show a California profilometer and a profilogram chart respectively.

Bureau of Public Roads Roughometer

The BPR roughometer, introduced in 1941, is a result of several efforts to obtain the true pavement profile. The roughometer is a trailer type device consisting of a single-wheel, suspended on two single leaf springs, on which is mounted a smooth 6.70 x 15, 4-ply tire. Pavement surface irregularities are recorded as differential movement of the



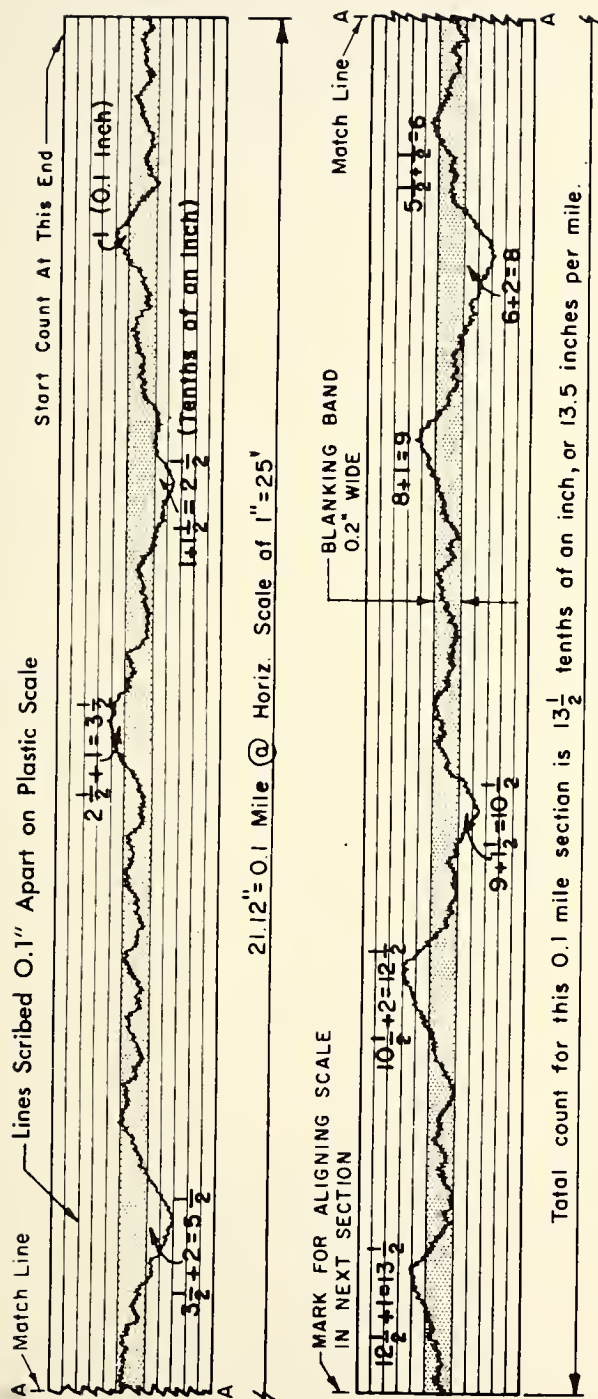
Figure 20

High Low Detector

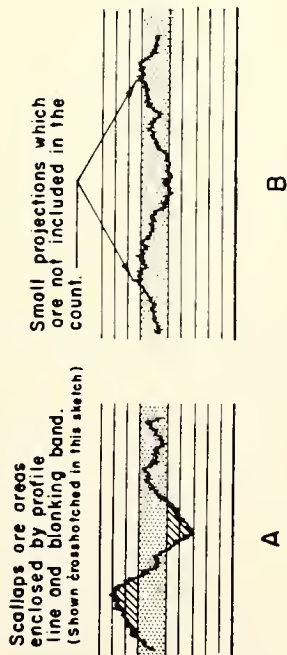


Figure 21

California Profilometer



TYPICAL CONDITIONS



SPECIAL CONDITIONS

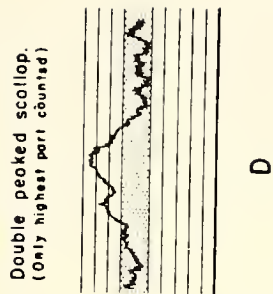


Figure 22

axle relative to the frame of the device. This movement is transmitted by a strong wire cable to a double acting ball-clutch integrator that converts the upward vertical motion to unidirectional rotary motion. This rotary motion actuates a micro switch that records the roughness in inches on a mechanical pulse counter in the towing machine (36). The roughometer is perhaps the most widely used roughness measuring equipment in the nation, having been put to use by 24 states in 1961. The State of Indiana has a device of this type which was used extensively by Mr. Halloway in 1956 (37) and by Mr. Milhous in 1964 (30,38).

Several modifications have been made to the original BPR unit. These include electronic and mechanical recording devices, and the incorporation of accelerometers and precision damping devices. Some of these modifications have been described by Petrok and Johnson of Minnesota (39) and by Ahlborn and Moyer of California (40). The ability of this type of equipment to measure the relative smoothness of a pavement consistently over a reasonable period of time has, however, been questioned. Variations have been observed and are suspected to be due to fluctuations in temperature and moisture (29). Figure 23 shows a modified version of the BPR equipment as manufactured by Soiltest. The equipment costs roughly \$16,000.

GMR Road Profilometer

According to Kelly and Spangler (41), the GMR road profilometer is the only existing equipment with the



Figure 23

BPR Roughometer as Manufactured by Soiltest

(Inset is an instrument panel inside the towing van)

capability of accurately measuring the true pavement profile. The road wheel, mounted on a trailing arm underneath the measuring vehicle, is held in contact with the ground with a 300-lb spring force. A potentiometer measures the relative motion of a point on the vehicle body and the road wheel. Signals from an accelerometer, mounted above the road wheel, and the potentiometer are inputs into an analog computer which integrates the acceleration signal twice and sums the resulting vertical motions to obtain the pavement's profile. The output of this computer is in the analog form, and extra labor is required to process the data to produce digital output. This is the equipment's major drawback. Figure 24 shows a schematic view of a GMR road profilometer.

PCA Roadmeter

This roadmeter is patterned after the CHLOE profilometer which measures the slope variance of the pavement's surface. The original PCA roadmeter is well described by Mr. Brokaw (42) of the PCA. A modification of the PCA roadmeter has been built by Soiltest. The equipment evaluates the pavement roughness by measuring the relative movements of the rear axle and the chassis of the test vehicle. These movements register on eight electrical counters in the console and are displayed digitally in a read-out window for each counter.

Plastigraph

An attachment to the slipform paver has been developed recently by Nebraska. This device plots the pavement profile

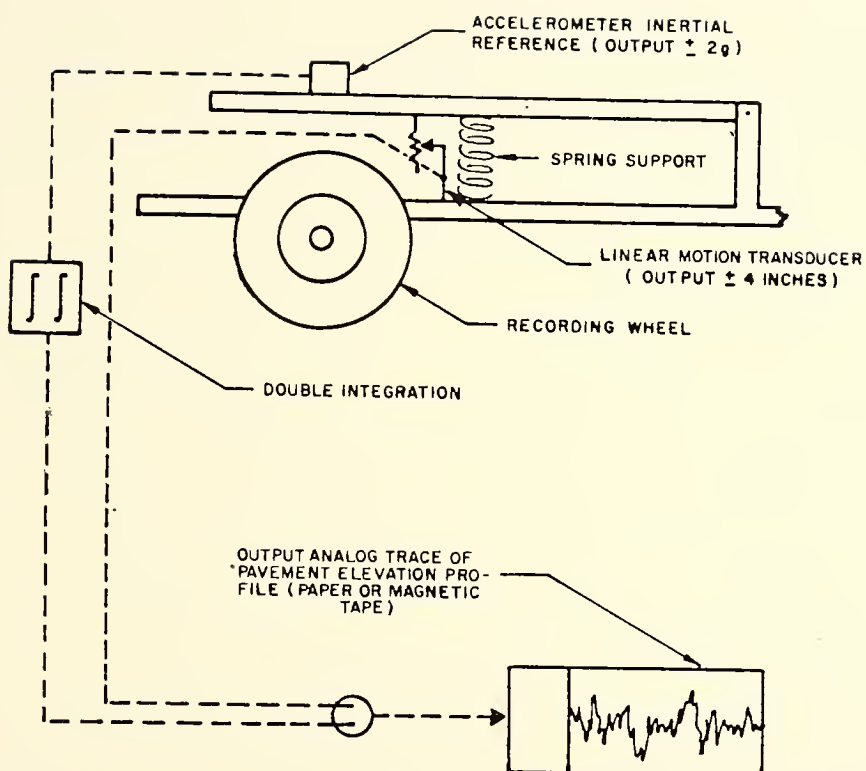


Figure 24

Schematic Diagram of GMR Road Profilometer

as an indication of roughness immediately behind the paving machine. The device is called a "Plastigraph" (24). If it can be shown to produce reliable and consistent readings, it may be what engineers and contractors have been waiting for since the development of Brown's "Viagraph" in 1900 (34).

Wet-Surface Profilometer

This device is used by engineers in Britain to check the smoothness of a plastic pavement. The unit consists essentially of a rigid frame whose wheel base is the same as that of the finishing machine. This frame supports two recording wheels in the same position, relative to the chassis, as that occupied by the trailing edge of the vibrating beam of the finisher. The recording wheels are set at the quarter points across the width of the slab, and are counter-balanced so that their contact with the concrete is just sufficient to rotate them. The rotating wheels actuate an integrator and a classifier. The profilometer records continuous longitudinal profiles and the integrator totals the upward vertical movements of the recording wheel, thus reflecting the pavement irregularities. The classifier registers automatically all irregularities in excess of 0.1 in over a range from 0.1 in up to 1.5 in. With this arrangement, a horizontal line indicates that the machine has produced the best surface possible, while any departure from the line indicates an irregularity (43). The machine has been used with form riding finishing machines, and has a potential for use with slipform paving.

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Factors That Govern Smoothness

The various factors which govern the smoothness of a slipformed pavement have already been described, and include the following:

1. The accuracy with which the subbase and subgrade have been prepared.
2. The consistency and uniformity of the concrete.
3. The rate of supply of the concrete, since this controls the rate of paving.
4. The experience of the equipment operator.

The accuracy obtained in preparing the subbase and subgrade becomes more important when the paving equipment takes its reference grade from these underlying layers, rather than from guide wires. If the paving equipment is of the first type, it is advisable to prepare the subgrade with an electronically-controlled subgrader. Unless the accuracy of the subgrade is assured, it should be checked before the paving operation is begun. Some states, such as Ohio, now require that all slipform pavers used within the state be equipped with guide wire systems to improve surface smoothness.

Proper consistency and uniformity of the concrete mix are also essential. A non-uniform concrete is difficult to consolidate. An extremely wet concrete tends to "boil up" behind the extrusion meter, and a very dry batch produces torn surfaces and unstable pavement edges. The best slump

for smooth paving, according to many contractors and manufacturers, is between 1- and 2-1/2-in.

Steady forward progress of the slipform paver is essential to secure pavement smoothness. This progress is controlled by the rate at which concrete is supplied to the paver. Stops should be held to a minimum, and it is better to slow the paver than to stop it completely. It is also essential to control the quality of the concrete in front of the paver. Excessive supply tends to lift the paver, resulting in a choppy surface.

An inexperienced operator will also have an adverse effect on the quality of the pavement produced by slip-forming. An experienced operator can look at the pavement and determine whether his equipment is well adjusted or not, or whether there have been variations in the concrete supplied to the job. The more an operator becomes experienced, the better the surface smoothness of the pavement he produces.

Paving Non-Standard Sections

Eyebrows are usually raised when one proposes the application of slipform techniques to the paving of non-standard sections such as steep slopes, ramps, warped crowns, and bridge decks. During the course of this research, several contractors, state highway officials, and equipment manufacturers were asked questions about their experiences in the applicability of slipform pavers to the paving

operations mentioned. The replies suggest that the slip-forming equipment, by reason of its versatility, is adaptable to most of those non-standard paving operations.

Ramps

Slipform pavers can be used, and have been used, to pave ramps. Many of the claims of the manufacturers with respect to ramp paving were confirmed by contractors and state highway officials. A few years ago both the Rex Chainbelt and the Guntert-Zimmerman machines were used to pave ramps and interchanges in Wyoming and Oklahoma (14). Gomaco's and CMI's machines have also been used to pave ramps without any difficulties (44, 45, 46) see Figure 25.

It was found, however, that ramp paving operation with a slipform paver is not easy. The normal crown has to be eliminated in a transition length of 100- to 120-ft before the start of the ramp curve. This operation involves a continuous electronic adjustment of the screed until the desired slope is obtained. This task is more difficult if the machine does not have electronic controls and, in fact, it is not advisable to use such equipment to pave ramps.

The optimum size of the machine used for ramp paving appears to be smaller than that normally used for straight line paving. This is because ramps are usually designed with variable widths along their lengths and it is not easy to adjust a large size machine to these variable widths.

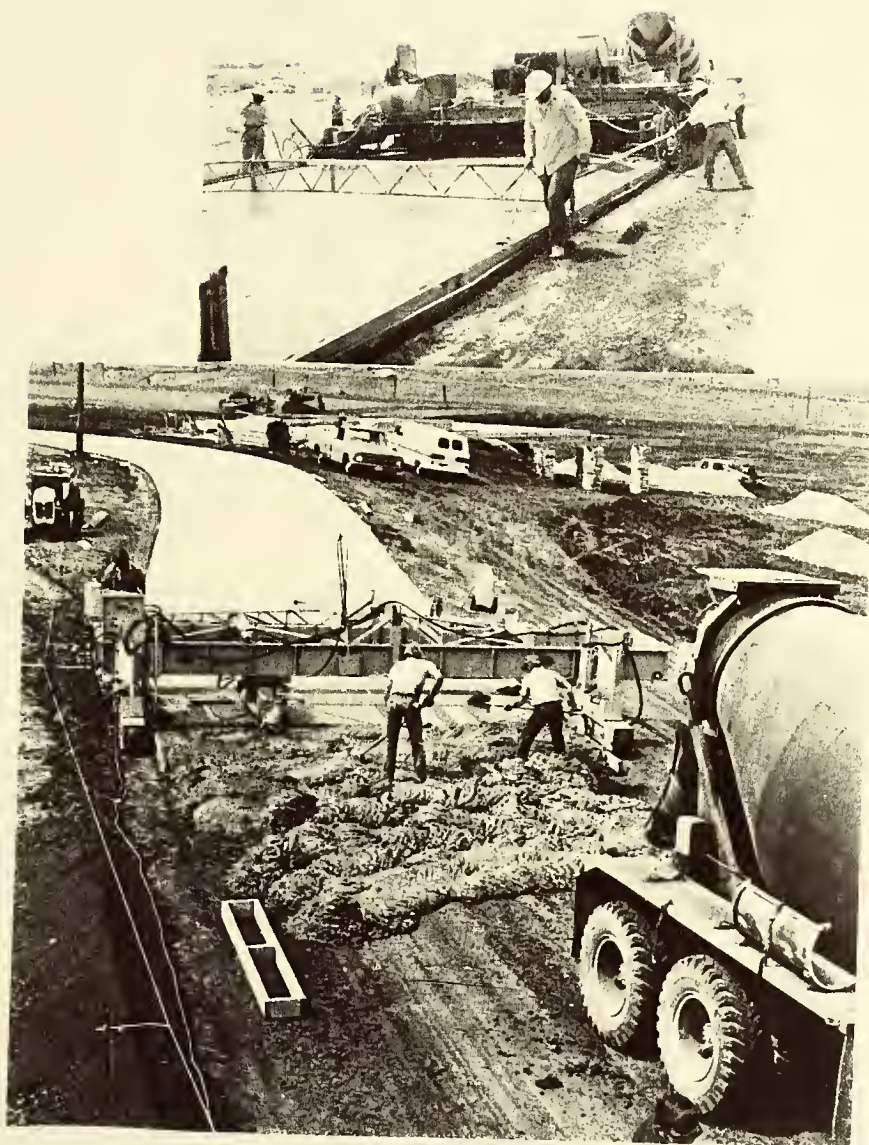


Figure 25

Slipform Pavers Used for Ramp Paving

Another problem with ramp paving is space limitation. It is claimed that the ramp designer usually does not provide adequate space for both the paving machine and the hauling units. It then becomes very difficult to accomodate these machines on ramps.

Several solutions for these problems have been proposed. Many equipment manufacturers have designed machines whose widths can be varied between 12- and 24-ft so that they can be used for both mainline and ramp paving; however these machines have not as yet become popular with contractors. Another proposed solution is to use 24-ft wide ramp pavements with the concrete shoulder areas delineated by paint stripes and rumble stripes. It has been claimed that a uniform ramp of this width can be paved at 25% less cost than a narrower variable-width ramp (26).

Another proposed solution is to standardize the geometric design of ramp widths. Variations for traffic delineation can then be made by a curb placed on top of the slab and/or by surfacing the shoulder area outside the curb with asphalt (22).

Some states have switched to uniform width ramp paving, but progress has been very slow. On the other hand, some states have eliminated the use of concrete pavements on ramps (26). Whatever the practice of any state, it is known that the present method of ramp design often complicates construction, slows production, creates unnecessary joints,

and often results in rougher riding surfaces. It is believed that considerable savings may be made by the use of uniform width ramps, or by easing the ramp smoothness requirement since ramp speeds are usually limited to between 20 to 45 mph as compared with mainline speeds of 60 to 75 mph. Ramp paving is usually part of the overall bid for portland cement concrete paving, and the actual cost of ramp work has thus been hidden. Some contractors contend that the true cost of ramp paving can run between \$8 to \$10 per sq yd.

Crowns

Another problem area in slipform paving is in the crown adjustment, especially for warped or parabolic crowns. Every slipform paver has a straight-slope rounded-crown as standard equipment and the console operator can adjust this crown to the desired height. When the design calls for a parabolic crown, the contractor either uses his ingenuity to produce it or just leaves the crown as it is extruded from the slipform. A change from a parabolic crown to a straight slope should reduce the cost of subbase, base and pavement, while eliminating the expense of incorporating adjustments for crowns into the equipment (22).

Many slipform equipment manufacturers now incorporate electronic crown adjustment into their machines. Rex has a machine in which an operator can select his crown ahead of time, or eliminate it entirely for paving a super-elevated

section. This is possible because of a built-in electronic device which surveys one side of the roadway, "senses" the change in the geometric design, and infinitely and gradually adjusts itself to the new section. The problem of adjustment for crowns is rapidly disappearing; the universal adoption of straight crowns would make the problem disappear even faster!

Slopes

Projects have been slipformed in California in which grades of 6% and superelevations of 12% were constructed. One of these projects was paved 3 lanes at a time (20). In some experimental projects in Ohio in 1964, slipform pavers were used on 7 to 8% grades. Contractors are of the opinion that the slipform paver can negotiate slopes of up to 12 to 15% without any choppiness or ill effects on the rideability of the paved surface. The equipment manufacturers indicate that the paver can satisfactorily pave any highway gradient which is encountered in this country. One manufacturer believes that its regular pavers can climb 30% slopes!

A new trend is to use slipformers to pave the sides of canals. In one instance, a slipform paver was used to pave the sides of a canal with side slopes of 1 on 2 (47°). Mr. Mike Hudis of Rex Chainbelt Company has stated that one of his company's units has been used to pave canals with side slopes of 47°. Gomaco company has a slope paver which is claimed to be able to negotiate slopes of 2 to 1 or steeper

without any concrete slump back. Guntert and Zimmerman units have been used in canal paving in California for several years.

Bridge Decks

Slipform pavers have not been used to pave bridge decks, and this application currently appears unlikely. The major reason is the limitation of space. To slipform a 24 ft bridge deck, it would be necessary to provide an additional 12 ft of travel width so that concrete trucks can make their delivery. Belt conveyors could then be used to transfer the concrete to the paver from these trucks. There would be a potential danger of the concrete setting before it reached the paver, since slipform pavers use low slump concrete. In addition, the cost of providing the 12 ft of travel width would almost certainly be more than any possible savings which could be realized from the slipforming process.

Sharp Curves

Slipform pavers can reportedly be used on radii as small as 100 ft. A slipform paver was tried on a radius of 60 ft in Columbus, Ohio, but could not turn adequately. Most slipform pavers will comfortably negotiate radii of 150 ft or more, which means that they can readily pave most of the interstate and state highways which are designed today.

Sidewalks, Curbs, Medians, etc.

Slipform pavers have been developed for paving curbs,

gutters, and various shapes of median (48). These machines are becoming as sophisticated as the big pavers. They can be equipped with automatic grade and slope controls and can operate from reference stringlines. They produce free-standing curbs of the required height and shape, and either integral or separate gutters of the desired cross-section (26). See Figure 26.

Originally, curbs were formed from cut stone, but as their cost became high and the need for street curbing became more critical, concrete replaced dimension stone. Initially, the concrete was pre-cast in the same sections as the stone curbs which they replaced, and then carried and placed on the job. With the advent of mobile transit-mix trucks, it became cheaper to handform concrete curbs on the job. Modern machines can now extrude curbs in place in a wide variety of shapes and sizes by merely changing a mold (49). These curbs can be extruded on existing pavements or on prepared subgrade. The machines can also extrude curbs in either concrete or asphalt.

The two major manufacturers of these machines are Curbmaster of America, Inc., located at Cedar Falls, Iowa; and Power Curbers, Inc. of Salisbury, North Carolina. Each of these companies manufactures various models with attachments for several shapes and sizes of curbs, gutters, ditches, medians and various radii. See Figure 27.

As mentioned previously, some large slipform equipment manufacturers have curb and gutter attachments for their



Figure 26

Slipform Curb Paver in Operation
(Notice the grade wires at the left side)

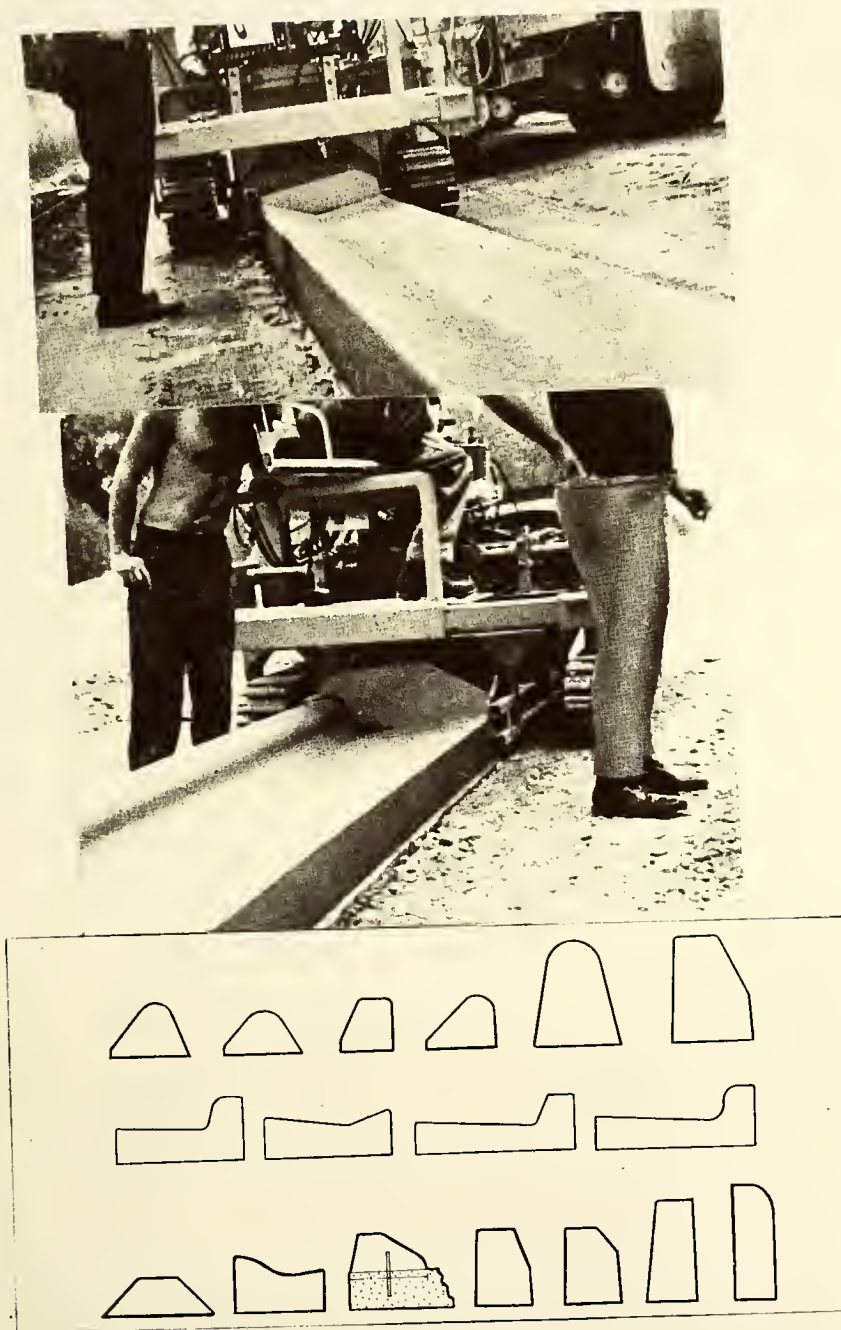


Figure 27

Various Sections Available with Curb Machines

slipform pavers. Rex Chainbelt Company claims to have been a pioneer in slipforming curbs and gutters, but it now only supplies such machines on request.

There are several advantages accompanying the use of the slipform curb and gutter machines, in addition to the elimination of side forms. Curb and gutter can be placed ahead of paving or can be tied into existing concrete slabs. Reinforcing bars can be fed through the machines, keyways can be extruded, expansion joints can be easily installed by the use of special templates after the machine has passed, and curbs can be lowered at driveway entrances (26). See Figures 28, 29 and 30. Time is the key to profit in construction work, and curb machines using concrete with slumps of between 0- to 1-1/2-inches and operating in the range of 6 ft per minute or more, can lay between 2000 to 3000 linear feet of concrete or asphalt curb per day. Not only is the paving time thus reduced but also the overall cost of the project is lowered. A Wisconsin contractor has cut his per foot cost by 20 cents (50)! The curb machines can also be used in areas of traffic channelization, highway water control, and parking lots. Their acceptance and use is rapidly growing, and one manufacturer claims that his equipment is used in all of 50 states and 30 overseas countries (49).

The Future of Slipform Paving

Every new idea, no matter how good it may be, requires time before it is accepted. The slipform paving technique

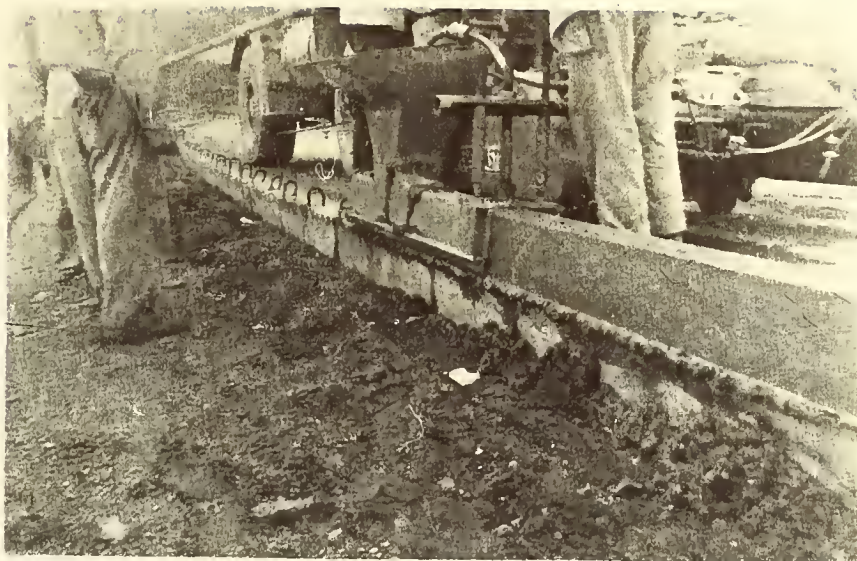


Figure 28

Curb Machine Being Used Over Dowels
on Hardened Concrete Coated with Epoxy



Figure 29

Preparing and Cutting Expansion Joint



Figure 30

Cutting a Driveway Entrance

is no exception to this principle. For many years some states refused to permit its use, either from lack of knowledge or from sheer entrenchment in old ways of doing things. This situation has existed in spite of the acceptance of slipform paving, at the federal level, for use on federally aided highways. However, since Colorado pioneered the use of a slipformer on its interstate system in 1956, the acceptance of the method has been accelerated. A contributing factor to this acceptance is the possibility of incorporating mesh in a slipformed slab. Today, there are only a few states where the method has not yet been completely accepted. Its future is promising.

Problems Encountered

Besides the initial reluctance of many highway officials to accept this technique, several problems have been encountered in its application. Many of these problems were inherited from sideform paving, but others are uniquely associated with the slipforming method.

Training of Contractors

When first introduced, slipforming was a new method of construction. It involved the use of new types of equipment and the retraining of men. It is not unexpected that many early slipform jobs were of marginal or substandard qualities. This is attested to by early experiences in California, Iowa, Oklahoma, and Colorado where the first one or two miles of a new slipform job were frequently unsatisfactory. However,

Multiple Lane Paving

Although most slipform pavers are used to pave 24 ft width slabs, machines have also been used to pave 36- and 48-ft wide slabs in one pass. These exceptionally wide or "king size" machines are suitable for multiple-lane urban streets. They have been so used in the West Coast, especially in California and Washington. The State of Indiana is allowing their use to pave a portion of I-65 south of Indianapolis. Here the contractor has been given the option of placing the three lanes in one pass; or placing the first 24 ft, then placing the remaining 12 ft by letting one side of the paver operate on the first 24 ft laid. The second alternative will delay the paving process, which could prove more expensive than single pass paving.

It is a major accomplishment for a unit, 36- or 48-ft in width, to travel at 6- to 15- fpm while adequately extruding, compacting, and shaping a slab 6- to 12-inches in thickness. Its successful accomplishment requires a thorough understanding of the slipforming process, plus accurate adjustment and expert operation of the machine. The future of these giant size machines for urban freeways and airport pavements looks bright.

Trailing Forms

Slipform pavers have come a long way from the initial stages when some states require 120 ft of trailing forms. Slipformers without trailing forms are now acceptable in

each succeeding mile saw a continuing improvement as the contractor became more familiar with the new method. Experienced contractors are now producing slipform pavement with qualities never attained with the side form paving technique.

The early history of bid prices on slipform paving suggests that contractors first approached this technique with reservations and caution. Many of the early bid prices did not reflect the potential savings of this technique. However, this situation has changed considerably as more contractors learn the "tricks of the trade".

Ramp Paving

Ramp paving by slipform is still a nightmare to many state highway officials and contractors. The major problems with ramp paving, as pointed out earlier, are the variable widths and the space limitations. Even when conventional side forms methods are used, ramp paving is very expensive. As a result, many states have relaxed their specifications to the point where it is feasible to employ the slipform paving technique on ramps. The state of Illinois now uses 16 ft uniform ramps, following the precedent of certain states which have used 24 ft widths and delineated the ramp width by markings. Other states are at present studying these modifications because of the potential savings if the slipform method can be applied. As pointed out earlier, slipform paving of ramps can save as much as 25% over the sideform technique.

those same states. This drastic change has come about from better understanding and increased confidence in the process, and also from continuous improvements by the manufacturers. Pavers are now available with built in edge formers which eliminate any need for trailing forms. These units have an advantage over those with trailing forms when it comes to ramp or curve paving. The long sections of trailing forms tend to leave rough edges on curve segments, and contractors with these machines will frequently find it necessary to revert to the use of side forms when they come to ramps or curves. The future looks promising, and it is expected that the slipform pavers of the future will require no forms on regular pavements, ramps, or interchanges.

Methods of Consolidation

The advent of the slipform paver has revealed our basic lack of knowledge concerning the vibration of concrete. At present, there is a lot of bickering over the size, weight, spacing, shape, frequency of vibration and type of vibrators to be used with a slipform paver. All these factors depend on the size and type of aggregate used, the consistency of the mix, and the condition of concrete placement. Efforts are now being made to find an "ideal" specification which will alleviate the current disputes. Such a specification, once it has been developed, can be modified by each state to satisfy its own conditions. Some states have banned the use of certain vibrators until further studies have been

completed. It is generally agreed that vibration is essential to proper concrete consolidation, but much remains to be learned about the subject.

Checking Depth and Smoothness

The need for better and more accurate equipment for checking slab depth and smoothness is becoming more and more imperative because of the speed of slipform paving. The nondestructive sonic and nuclear devices should be developed as quickly as possible. The taking of five to ten concrete cores per lane mile of pavement is unacceptable, both because the test is a destructive one and because the samples are too few in number to permit a statistical verification of their findings.

Pavement smoothness is an indication of service life, with the smoother pavements lasting longer. A slipformed pavement is usually found to be superior to a sideformed pavement in smoothness and in "riding quality". Of course, riding quality is a complicated factor to measure because it depends on three separate systems and the interactions between them. These systems are the highway user, the vehicle, and the pavement they are riding on. The measurement of riding quality therefore requires the development of a suitable mathematical model to describe the suspension characteristics of highway vehicles, a roughness model to predict the dynamic responses of these vehicles, and a quantitative knowledge of the response of humans to motion (29).

Even if the first two hurdles were overcome, there still remains the problem of evaluating the response of humans to motion.

Most equipment for measuring smoothness can be used only on hardened pavement. The development of the Nebraska plastigraph is a step in the right direction, since this unit can be used to check the smoothness of a plastic pavement. The industry is looking to the day when an equipment operator will be able to press some buttons on his equipment and be able to read the pavement thickness and surface roughness from his instrument panel. It may not occur in this decade, or even in the next, but the groundwork has been laid and further research will make this goal possible.

Production Capability

How fast should a slipform paving machine travel? This is a question which bothers many highway officials. Some have gone to the extent of limiting the travel speed of a paver to a maximum of 12 fpm. This is a crippling action and should not be taken without adequate justification. The equipment manufacturers are generally agreed that speeds of about 15- to 20-fpm are satisfactory for the present equipment. Operations during which Matich of California laid 12,413 ft, Barton of Minnesota laid 13,240 ft, and Denton of Michigan laid 13,965 ft in one paving day attest to the paving capacities of slipform machines. It is obvious that such achievements would not be possible with a top speed of

12 fpm. The concern should be directed towards the development of concrete plants that will be able to supply these machines, rather than to the maximum permissible speeds for paving. The most common central plants can only produce a maximum of 600 cu yds per hour, just enough to handle a paving operation at 15 fpm. Many slipform machines can travel at twice this rate, with a demonstrated capacity for acceptable paving.

New Markets, Materials, and Ideas

The slipform paving concept is not limited to highway and street-accessory paving. It has been used successfully for airports, industrial floors, and canals. The manufacture of new cement products is also proving adaptable to slipform paving technique. New ideas are being nursed and applied by manufacturers and contractors. All these efforts are uniquely and individually contributing to the continued success of the slipform paving process.

New Markets

The use of the slipform paving technique is gradually spreading to other countries and other areas of paving. Slipformers have already been used in France, Britain, Japan and Canada. New application areas for the slipform paving technique are also being developed. The use of slipform pavers for paving airport runways, taxiways, and aprons is rapidly gaining ground in this country and in other parts of the world. Slipformers have been used for airports in

California, Texas and Maine. Some airports that were slip-formed about 16 years ago are still in satisfactory condition. Besides the smoother and denser slabs that have been obtained, estimated savings of as much as \$2.00 per cu yd have been realized (51).

France is a leader in the use of slipform pavers for airfield construction. More recently, airfields near Brest and in Paris were slipformed using Rex and Guntert-Zimmerman pavers.

Slipformers have been used extensively for canals and ditches for many years in California. In fact, the Guntert and Zimmerman Company manufactured canal slipformers before entering the highway slipformer market a few years ago.

Another area in which slipformers have been tried is in the paving of industrial floors. The reported result was a better and cheaper floor than that obtained by conventional methods.

New Cement Products

There are two new types of cement now on the market which may have application to the slipform paving technique. These two types, known as Regulated Set Cement and Shrinkage Compensated or Expansive Cement, are hydraulic cements which were recently developed in the laboratories of the University of California.

The regulated set or "reg set" cement has a setting time which can be controlled from approximately one or two minutes to about 30 minutes, with corresponding rapid

strength increase. It is a modified portland cement and can be manufactured in the same kiln used for standard portland cement. Various formulations can adjust its high early strength levels in accordance with the application needs. The cement is presently available in limited quantities. Its identifiable highway applications include highway and bridge deck patching and resurfacing.

The expansive cement, "Chem Comp" or shrinkage compensated cement is a type that expands during the early hardening process. It has been found to reduce cracking when used in conjunction with reinforcing steel in pavements. It has many uses outside of highway construction.

These new cement products do not appear to be suited to the slipform paving techniques which are currently in use. However, further research may change this situation. The regulated set cement, in particular, may prove compatible with slipforming. The shrinkage compensating cement is considerably less promising, since it has to be restrained, by forms or otherwise, for a period of several days in order to realize its inherent capabilities. The cement market for slipforming is still confined to types I and II.

New Ideas

The biggest advancement in slipform paving is the possibility of incorporating steel reinforcement in the concrete slab. Initial efforts to incorporate this steel in one lift remained unsuccessful until the necessary

equipment had been developed. At present, both mesh, bar mats and deformed bars can be depressed in one continuous operation as the slab is being laid. The most recent of these techniques, which makes use of a unit called a "Rebar Installer" which is manufactured by Rex Chainbelt, Inc., is winning greater and greater acceptance. It appears to be the best technique so far developed for placing reinforcing steel, and many contractors have built their own equipment along similar lines.

The slipform paver as it is today has come a long way from the original machine as built 20 years ago. Many innovation and ideas are still in the offing, and the slipform paver is not yet fully perfected. There are many areas where contractors, highway engineers, material producers, manufacturers, and researchers must work together to develop the ultimate capabilities of the slipform paver.

PART II

METHODS OF PLACING REINFORCING STEEL

FOR THE SLIPFORM CONSTRUCTION OF

CONTINUOUSLY REINFORCED CONCRETE

PAVEMENTS

PART II - METHODS OF PLACING REINFORCING STEEL FOR
THE SLIPFORM CONSTRUCTION OF CONTINUOUSLY
REINFORCED CONCRETE PAVEMENTS

Evaluation of Continuously Reinforced Pavement

Portland cement concrete, because of specific physical properties which it possesses, has been a favored material for the construction of highway pavements. These properties include structural strength, durability, adaptability to meeting exact design requirements, skid-resistant surface, and good night visibility whether wet or dry (52). However, not all the physical properties of concrete contribute to good performance of the pavement. Concrete is subject to relatively-large volume changes during early cement hydration, and to subsequent volume changes due to variation in temperature and moisture. Concrete also has low tensile strength and this, if restraint conditions inhibit volumetric expansion due to increased temperature and/or moisture, can lead to characteristic cracking. Loading conditions can also produce tensile stresses which exceed the tensile strength of the concrete, resulting in longitudinal and/or transverse cracks in the pavement slab.

The basic purpose of combining steel with concrete in highway pavements is to utilize the ductility and high tensile

strength of steel to compensate for the inherent brittleness and relatively low tensile strength of concrete (7). Reinforcement, even though it does not eliminate cracking, helps to hold the fractured portions of the pavement together. This reduces their relative displacements and thereby prolongs the service life of the slab (53).

Cracks, regardless of their origin, are points of structural weaknesses in a pavement. They permit surface moisture to enter and saturate the subgrade, thus reducing its strength and contributing to the risk of mud pumping and pavement blow-ups. Cracks in a concrete pavement can become serious maintenance problems (6). For many years, highway engineers have attempted to minimize pavement cracking to prevent spreading of cracks once formed, and to reduce their adverse effects on pavement performance. The answer to longitudinal cracking was found to be the longitudinal joint which, since its successful performance in the Bates Experimental Road, has become an almost universally accepted design feature (54). However, the problem of transverse cracking still remains. The usual approach to its control is centered around the use of joints spaced at distances varying from 15- to 1000-ft. In addition, steel reinforcement may be added to provide additional tensile strength or to transfer loads between adjacent pavement slabs. Attention has also been directed to the use of prestressed concrete slabs and shrinkage compensated cements.

The results of controlling transverse cracks by the use of transverse joints have not been entirely satisfactory. In fact, these controlled joints have been found to possess most of the undesirable characteristics of the natural cracks which they are intended to eliminate. They are also great obstacles to comfortable travel. Therefore current efforts have been directed towards the complete elimination of transverse joints by constructing continuously reinforced concrete pavement.

Continuously reinforced concrete (CRC) pavement is a portland cement concrete pavement with continuous longitudinal steel reinforcement. Continuity is achieved by lapping the steel and placing the concrete continuously for long distances without transverse joints. The laps are usually 16- to 18-ins long. The only transverse joints required are construction joints at the end of the day's work - which usually means spacings of a mile or more. Joints are also introduced when continuous paving is delayed sufficiently so that there is danger of the concrete hardening or when paving is interrupted by bridges or by other traffic structures. The structural continuity of the slab, achieved by continuous lapping of steel, allows the slab to function as a unit for its entire length. It also restrains longitudinal warping (3).

CRC pavement is usually reinforced with deformed bars or bar mats, with steel percentages which are up to 2-1/2 times as large as the distributed steel in conventionally reinforced pavements. A normal amount of longitudinal reinforcement

for CRC, assuming steel with a minimum yeild strength of 60,000 psi, is 0.6% of the gross sectional area of the pavement. Reinforcements of 0.5- to 0.7-% have also been tried (54)(55). The extra heavy steel gives added strength to the pavement and holds it together during even the widest temperature variations.

Numerous but very narrow transverse cracks will develop in a controlled and predictable pattern on the CRC pavement shortly after construction. However, these cracks are not subject to progressive deterioration. Measurements made on experimental pavements with approximately 0.6% longitudinal steel showed surface crack widths from 0.003 in. to 0.031 in. Cores taken from these slabs indicated that these surface cracks rapidly narrowed in width as they extended downward to the level of the reinforcement (6)(54). Tests have indicated that the cracks in CRC pavement are held so closely together that aggregate interlock remains effective, load transfer and stress reducing properties are retained at high levels, and the structural integrity of the slab is maintained. The cracks are not objectionable to motorists because they are not visible from a vehicle travelling at more than 20 mph and, as previously mentioned they are not subject to progressive deterioration. These conclusions have been derived from experimental projects and from the performance of a pavement, in Illinois, which showed no significant steel corrosion after 18 years of service. See Figure 31. Because of their tightness, the cracks require

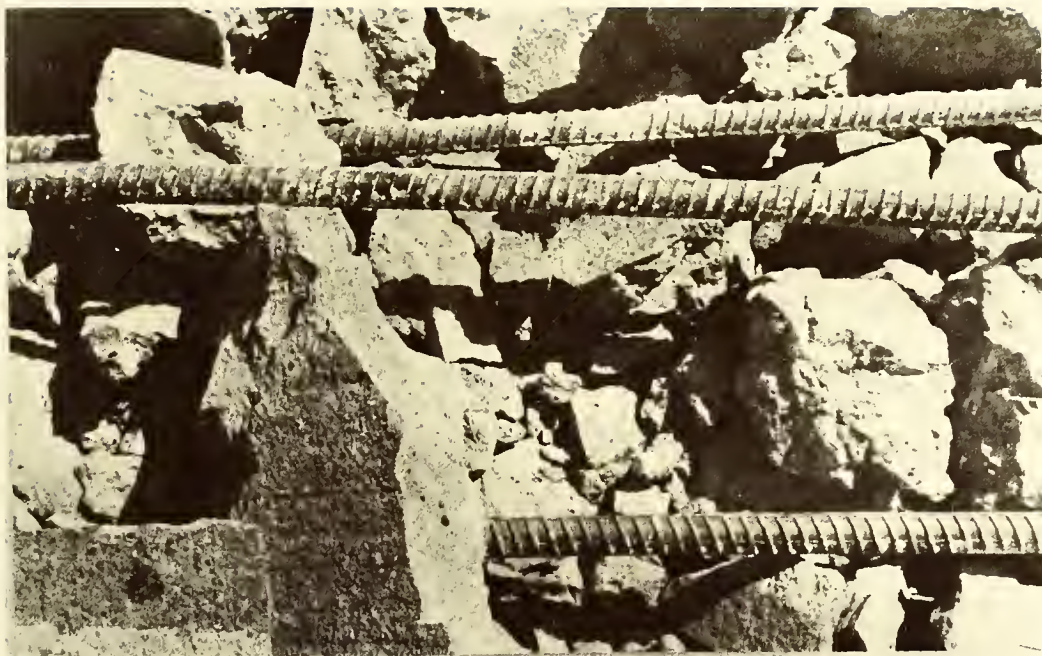


Figure 31

Reinforcing Bars Removed From CRC Pavement

After 18 Years of Service

(Rust scale was absent even though an average
of 7 tons of de-icing salts were used per mile
per year)

no periodic cleaning and sealing, thereby sharply reducing maintenance costs and irritating interference with travel (6).

After research and development spanning almost 45 years, during which an experimental pavement was built on I-40 near Stilesville, Indiana in 1938, continuously reinforced pavement is now the fastest growing pavement design in use today. The mileage constructed or under contract in the United States has grown from 100 mile equivalent of 2-lane miles in 1959 in 8 states to 7,524 miles in 1969 in 25 states (55)(56). This fast acceptance has been added by improved and standardized design formulas, particularly for steel content and slab thickness; by different methods of mechanically assembling and placing reinforcement; by use of slipform pavers which are adaptable to continuous reinforcement; and by faster and more economical construction through improved job organization and management (52). Although there have been some attendant problems of construction, such as inadequate consolidation, improper positioning of steel, and inadequate subgrade preparation, continuous reinforcement, today, appears to be the most promising method of controlling transverse cracks in concrete pavement.

Many highway design and construction engineers regard the development of CRC pavement and the acceptance of the slipform paver as timely because of the increasing pressure for better highways at acceptable cost and for greater safety for highway users despite continuing vehicular

traffic increases. The experience with experimental pavements that have been in service for more than 40 years, such as that on Columbia Pike in Washington D.C., strongly suggests that continuously reinforced pavement is a significant improvement over the conventionally jointed pavement. Besides retaining all the advantages of jointed pavement, CRC pavement offers the added features of smoother riding; longer pavement life; fewer travel interruptions attributable to pavement maintenance problems; and the complete elimination of such safety hazards as spalling, bumps and blow-ups. Admittedly, there is still a lot to be known about CRC pavement, but what is known so far is very encouraging. Many State Highway Commissions, Indiana's included, have consequently decided to use CRC pavements on all interstate and state highways.

It has long been theorized that the actual function of transverse reinforcement is to properly space the longitudinal reinforcement. Therefore, if the longitudinal reinforcement can be properly spaced by other means, transverse reinforcement will not be necessary. The trend of states now is towards the elimination of transverse steel. The State of Iowa set the pace in 1965 by letting the contractor omit transverse steel when longitudinal steel was well positioned (57). Since then, other states have adopted the same practice. To date, six states around the country have eliminated the use of transverse bars and many more are

considering the move. The states that have eliminated transverse steel are North Dakota, Wisconsin, South Carolina, North Carolina, Iowa, and Virginia (55). Maryland has approved the move and Indiana has let out a job on I-65 south of Indianapolis on which transverse reinforcement will be eliminated.

The deletion of transverse reinforcement has generally resulted in a reduction in bid prices through savings in material and labor. On the first job, in Iowa, without transverse steel, as much as \$0.50 per sq yd was saved in material and labor (57). Fifteen states, in replying to a questionnaire concerning CRC pavements, supplied estimates of savings due to the elimination of transverse bars which ran between \$0.15 and \$0.50 per sq yd. (See States' Acceptance of Mechanical Steel Placing Methods on page 158). It is probably too early to estimate categorically there will or will not be any long range unfavorable effects on the pavement, but the pavements laid without transverse reinforcement in Iowa five years ago are still trouble-free.

Over the years, many methods of construction of CRC pavements have been developed. Most of these methods permit the omission of transverse bars. When transverse bars are specified, they are positioned by notched rotating drums or tied to the longitudinal steel before placement, depending on the position specified. These techniques have drastically reduced the steel placing labor requirements and have made possible the placement of daily footages of CRC pavement

which were never attainable in the history of conventionally reinforced pavement construction.

To accomodate these new methods, many states have modified their tolerance specifications for the positioning of steel, (See States' Acceptance of Mechanical Steel Placing Methods on Page 158), and have thus been able to make even greater savings.

Methods of Placing Reinforcing Steel for CRC Pavement Slipforming

Background

Ever since highway pavement construction has involved the incorporation of steel in concrete slabs, contractors have been seeking more economical methods for installing the reinforcement. The most common of the earlier techniques involved the use of chair supports for the wire mesh or bar mats. Between forty to sixty men were frequently required to place the reinforcing steel on chairs. Another method required a two-lift concrete placing technique, with the reinforcement sandwiched between the two layers of concrete. Such methods were not entirely satisfactory, but were able to survive for a long time. They were compatible with the slow paving pace, and also there were no other acceptable ways for placing reinforcement. This situation changed with the introduction of the slipform paving technique and the development of continuously reinforced pavement. The contractors and highway engineers realized that better and more

economical methods for laying reinforcing steel would have to be found, in order to realize the full potentials of slipforming and CRC pavements. Setting reinforcement is now the most costly single operation in the construction of concrete pavements, and contractors have developed various devices to improve its performance. Many of these innovations were opposed by state officials who felt that the new paving developments, slipform and CRC pavement, should be adapted to the established techniques of chair supports and "sandwiching". This bias was evidenced by specifications which did not allow the use of slipforms unless reinforcement was supported on chairs; or which allowed steel to be placed in two lifts when side forms were used, but not when slipforms were used; or which allowed steel to be depressed from the surface by vibration when sideforms were used, but not with slipforms. These and other artificial restrictions arose, presumably due to a lack of knowledge and a fear of doing something in a way different from the "conventional". Such unwarranted restrictions acted to the detriment of the public by increasing the costs of highway construction without commensurate benefits.

While slipform paving may be one of the most dramatic departures from "standard" paving procedures, it certainly is not the only one. New procedures have been introduced whereby bars, bar mats, and mesh are laid by mechanical means to facilitate one lift paving. These mechanical reinforcing placers are a recent development, being first

introduced in Oregon in 1960 (58). Most of them were initially used with formed paving until specifications were relaxed to permit their use for the slipform paving of CRC pavements. Today, both mesh and heavy continuous reinforcement are being laid faster and easier than was ever before possible. Contractors who felt lucky to reach 2000 ft a day not many years ago, now think nothing of laying 4000- to 6000-ft of CRC steel, day after day (57). This change has come about from mechanization of the steel-laying process. Contractors have developed and built machines to satisfy their local specifications, and some of these machines are now proving nationally applicable. Equipment manufacturers are also making their contributions. For example, in the last decade, Rex Chainbelt, Inc., has developed two units, one for laying mesh and the other for laying bars. The new equipment units have caused substantial reductions in the paving costs for those states in which their uses have been permitted. Also, when the units are properly employed, the results obtained with them have been very satisfactory.

Steel was successfully incorporated in a slipformed pavement in Oklahoma in 1964, using the two-lift method. Rex Chainbelt's mesh depressor was introduced in 1965 as an attachment to the slipform paver, but for many years the states' specifications limited its use to slipformed jointed pavements. During this period, slipformed CRC pavements continued to be laid with chair supports until 1967 when a

Minnesota contractor successfully slipformed the first CRC pavement to be constructed without the use of chair supports. His method was that of sandwiching the steel between two layers of plastic concrete before slipforming. It then became apparent that many of the steel installation techniques that had been used with jointed slipform pavements could also be used with CRC pavements. This realization now gives the highway user a greater chance of getting the best quality pavements for his tax dollar than ever before possible. Highway construction can now benefit from the several labor and time saving modifications which have been introduced for the slipform paving of continuously reinforced concrete pavements.

The following section of this report will describe the techniques that have been used or are being used to place reinforcing steel in CRC pavement slipforming. It will also supply an evaluation of each technique, based on the experiences of contractors and states in which these methods have been tried. The techniques reported herein were employed in Indiana, Iowa, Illinois, Minnesota and North Dakota during the summer of 1970 and were observed as a part of this study.

Chair Supports

Chair support is one of the earliest methods used to support reinforcement so that the slab can be placed in a single lift. Its use dates back to the construction of the

first reinforced portalnd cement concrete pavement. For many years it was the accepted method for all formed and jointed pavements. When the paving industry was revolutionized by slipform and CRC pavement, its use continued to be a requirement in many highway specifications.

When steel is to be placed on chair supports, the first step is to spot the chairs at the spacings called for in the specifications. This can be done by using a tape or a template which marks the specified positions along the subgrade. When individual high chairs are to be used, these are first tied, welded, or clipped to the transverse bars. See Figure 32 for types of individual high chairs in current use. However, the more recent technique is the use of continuous high chairs as shown in Figure 33. After the chairs are in position, the reinforcement, whether mesh or bars, can be placed by hand or by any labor saving device that the contractor may have at his disposal.

In positioning mesh, contractors have devised means that have varied from conventional mobile cranes to sophisticated electric magnets and solenoids. A review of these methods is considered unnecessary here since each contractor is free to use his ingenuity to devise and build any machine to help him cut labor and time on any construction operation. Positioning reinforcing rods is generally performed by hand, although hooks and slings have been used as shown in Figure 34.

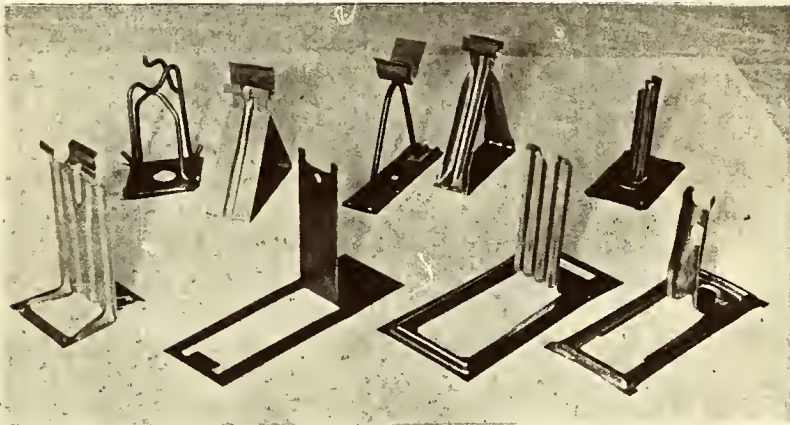


Figure 32

Various Types of Individual High Chairs
for Supporting Reinforcement

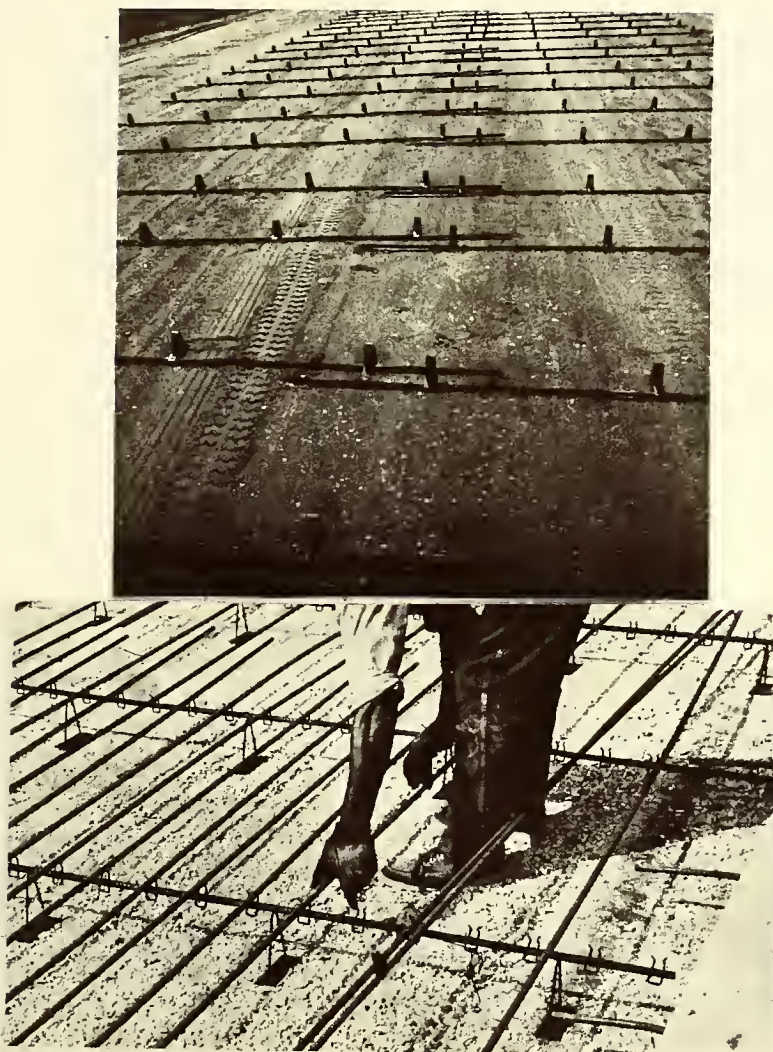


Figure 33

Newer Types of Continuous High Chairs



Figure 34

Ways of Positioning Reinforcing Bars on Chair Supports

After the steel is positioned on the chairs, it is lapped and tied to the transverse bars. The concrete is then placed by the slipform paver through and around the steel framework on the subgrade.

For many years, specifications have stated that reinforcement must be supported on chairs only. In addition, where precise tolerances are specified for steel placement, such as $\pm 1/4$ in. of vertical displacement from the specified height and $1/2$ in. displacement laterally, the contractor is left with no other choice than to use chairs. However, there are many disadvantages accompanying the use of chair supports.

The major disadvantage is the amount of labor and time expended in placing the chairs. On the average, it takes between 40 to 60 men working constantly for 10 hours to lay about 2000 ft of steel. With the paving techniques available today, this means that the steel laying operation will have to be started several weeks ahead of the paving operation. This results in delays and losses of useful hours and labor that could have been directed to other operations. The contractor is aware of this, and his bids reflect the anticipated lost time and money. For example, average 1969 bid prices in Indiana for CRC pavement with chair supports ran as high as \$8.00 per sq yd for 9 in. pavement, as compared with less than \$7.00 per sq yd for the same type of pavement built without chairs in Iowa (57).

A leading Indiana contractor asserts that chairs cost up to \$0.20 per sq yd and that the labor cost to place them amounts to approximately the same amount.

Highway officials claim that the use of chair supports gives them more confidence that the steel is correctly positioned in the pavement. One wonders if this is really true after observing the way pit men walk on the chairs while spreading concrete, thereby tending to bend the chairs out of position (See Figure 35). It is entirely possible that chair supports do not actually accomplish the purpose for which they are specified, at least in sufficient degree to warrant their continued use when better and less expensive placement methods are available. It is hoped that highway specification writers will examine all pertinent factors, rather than display a rigid adherence to the use of chair supports when better methods are available at no greater expense.

Two-Lift, or "Strike-Off" Technique

One of the earliest methods for eliminating the laboriously placed chairs was the two lift technique. This method has been used mostly for placing reinforcing mesh and bar mats. It has never been popular because of its inherent weaknesses, and Indiana specification definitely forbids its use.

The method involves placing the first layer of concrete and striking it off at the height specified for the



Figure 35

A Chair Bent Out of Position

(One or more adjacent chairs bent will definitely not ensure proper elevation when concrete is poured)

reinforcement. This first lift of concrete is usually between 0- to 12-ins. short of the width of the pavement (59). The wire mesh or bar mat is then laid on the concrete platform and the rest of the slab is placed and finished by a slipform paver. The entire paving operation must be carried on continuously so that the upper layer of concrete is placed before the lower layer begins to set.

This method was used with the first reinforced slipform job in 1964 in Oklahoma. Prior to that, up until the middle 1950's, it was the generally preferred method for placing mesh in conventionally constructed pavements (7)(60). Its advocates correctly claimed that the placement of the second layer before the first layer had begun to set would ensure a good bond between the two layers. They also claimed that the reinforcement would be supported firmly and accurately in its correct position and the necessary walking by the laborers would not bend or distort the steel to any appreciable extent.

The slipform pavements constructed by this method have been quite satisfactory, but the attendant problems are quite obvious. The method depends on a continuous supply of concrete, which must be delivered and placed as quickly as possible. Any delay caused by breakdown of the plant or hauling units can result in a plane of weakness between the two slab layers. On a hot day, additional precautions are needed to ensure that the water content on the surface of

the first layer is not appreciably reduced. If a significant loss of water is experienced, there will not be enough water to hydrate the second layer. A plane of weakness and poor bond will therefore develop between the two layers.

Another important disadvantage is that two spreaders or slipform pavers are usually required to perform the two lift operation. This wastes time, money, and manpower since workers will have to be transferred back and forth between operations.

Because of these disadvantages, this method is not recommended by many states, including Indiana, or by the Continuously Reinforced Pavement Group (6). Many contractors also object to its use because it requires an additional investment in equipment.

Sleds

Another device used to place reinforcement in conjunction with the slipform technique is the sled. The method was used mostly with mesh and bar mats.

The process involves attaching a sled type device to the front of the slipform paver. The sled consists of a series of parallel steel members on runners which are connected at one end by a steel cross member. The sled is placed on the subgrade and the runners are spaced so that they can pass between the dowels which are supported on the subbase. The sheets of wire fabric or bar mats are usually laid out on the subgrade in advance and tied together at

laps to form a continuous length of reinforcement. As the paver moves forward, the wire fabric is lifted into position and the concrete is deposited through and around the mesh. Consolidation and finishing are performed in the usual ways (59) (60) (61).

There are several serious objections to the use of sleds. The steel is supported on rollers, and if these are not rolling freely, then enough friction develops between them and the rollers to pull the steel in the concrete and create planes of weakness in the slab. Another disadvantage is the possibility of interfering with the depositing of concrete, therefore delaying paving operation. As mentioned earlier, this method is not a popular one and has not been recommended by many states.

Mechanical Methods of Placing Mesh

Mesh Depressors

The mesh depressor was the first break through in the contractors' search for machines to place reinforcement in one lift. It was used in Oregon in 1960, in Louisiana in 1961, and in Indiana in 1962 (58). This early development rode on forms and used vibration and pressure to depress the steel. It depressed the steel while standing at rest, thereby eliminating lateral displacement of the mesh during depression. The machine was self-propelled and carried four hydraulic rams under which was suspended a latticed steel

frame. On the frame at each ram was a vibrator. Limit chains were used to halt the frame at the correct depth of mesh embedment. The rams then retracted the frame for the next sinking cycle (62).

A similar type of unit was used by the Traylor Brothers on I-65 in Indiana in 1962. This machine consisted of a giant screen or grid which vibrated and depressed the sheet of fabric to its proper depth. The unit was fitted with large depressing units which left a "waffle" pattern on the concrete. Its pressing depth was governed by adjustable lock nuts on threaded guide rods instead of by limit chains. The machine performed very satisfactorily, judged by the analyses of core samples. Air entrainment tests showed loss of less than 0.1% of air due to the placing operation. Apparently, the Traylor Brothers and the Oregon contractor developed their machines independently. The Traylor Brothers had asked to develop and use the Oregon type of machine back in 1958, but were turned down.

The current manufacturers of mesh depressors are Heltzel Steel Form Company, Rex Chainbelt Company, and CMI, Incorporated. Each of these companies produces a single model which can be used either with side form or slipform paving. The Heltzel's machine is a self-propelled unit, while the other two are attachments to slipform pavers, spreaders or finishers.

Heltzel Mesh Depressor

The Heltzel Company unit is adjustable in width from 12- to 24-ft, and appears to be similar in its design and operation to the two contractor-built devices just described. It carries four grids with vibration runners on 20- x 23 in. centers. Each grid consists of 4 blades welded to the vibrator housing. The basic length of the grid is 10 ft, with detachable end sections providing for a total length of 15 ft. The machine depresses steel from the surface of the full depth slab. Mesh is placed on the surface of the slab and the machine moves forward to position directly over the mesh. As the mesh depressor comes to a full stop, its operator actuates the vibration grids and the hydraulic pressure which depress the mesh into the concrete. After the mesh has been depressed to the proper depth, hydraulic cylinders lift the grids from the concrete and the machine moves to the next position. The operation of depressing the steel takes between 10 to 18 seconds and leaves a waffle pattern on the slab (see Figures 36 and 37).

Vibration and pressure are the major factors responsible for sinking the bar mats. Vibration causes the movement of the wire down into the mix by helping aggregates to move slightly aside. Although the machine stands squarely on the mesh which is being depressed, a length of 1 ft or more of the next mesh at the point of overlap is also depressed in sympathy. This eliminates the possibility of the next sheet getting caught as the machine moves forward. It also

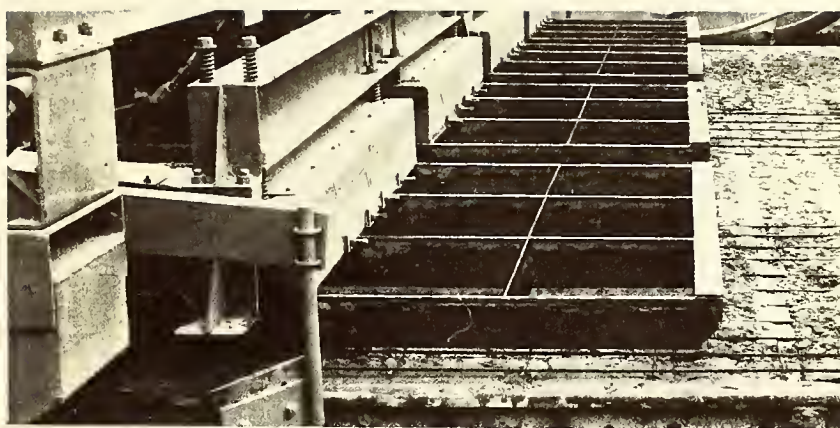


Figure 36

Hydraulic Cylinders Raise Grids as Machine Moves to Position



Figure 37

Machine Leaves a Waffle Pattern as it Moves Forward

eliminates the need for more extensive vibration of the concrete after the depression cycle. This type of machine was used for CRC side form paving on I-69 near Indianapolis during the summer of 1970.

Mr. Mathews, the Field Sales representative for the Heltzel unit, has supplied additional information in response to questions posed by the author. According to Mr. Mathews, there is no possibility for aggregate segregation because of the type of mix and because of the short time the machine takes to depress the steel. This claim is supported by examination of cores taken from job sites (Figure 38), and by reports from several states in which the machine has been used. The machine reportedly can depress bar mats as well as mesh; and it can also depress individual bars. If these are properly spaced on the surface of the concrete. Notches are cut in the grids to align and engage individual bars to ensure their correct spacing while being depressed. Some changes have been made to the machine since its introduction, and further changes are planned. The machine can be equipped with tracks to facilitate slipform paving.

Rex Chainbelt Mesh Depressor

The Rex Chainbelt Company introduced its mesh depressor in 1962 after a pilot model had been tested in Illinois. The unit was an attachment to a standard finishing machine and rode on forms in front of the finisher. It was designed to gently tamp the wire reinforcement and press it down gradually as the finisher moved forward. The action of the depressor could be controlled from the operator console (63).



Figure 38

Cores Show no Aggregate Segregation

The current model of the Rex mesh depressor was introduced in 1965. It is a complete modification which rides on crawler tracks and is an attachment to the front of a placer or slipform paver. It consists essentially of a set of blades, in two banks, which is attached to a frame. Within the frame is a mechanism of gears and springs which is arranged for an eccentric movement with an amplitude of $3/4$ in. This arrangement imparts a type of oscillatory motion to the blades. The resulting tamping and tucking action makes continuous placement possible without vibration (see Figure 39). The final depth for steel depends on the setting of the rear end of the blades. Both the blades and their slopes can be adjusted for the conditions of paving. The depressor blades are evenly spaced across the full slab width and can depress mesh to depths of 6 in. The depressor units are hydraulically lifted to pass over dowel brackets and crown adjustments are made from the slipform or placer console. This machine has been used to the satisfaction of many state officials.

CMI Mesh Depressor

A third type of mesh depressor is manufactured by CMI, Inc. This machine attaches to the front of a slipform paver and depresses the mesh into the mix, using high frequency vibration and low amplitude. The blades are vibrated at 2000 to 4000 cps with an amplitude of $1/8$ in. Vertical baffles are responsible for pushing the steel into the

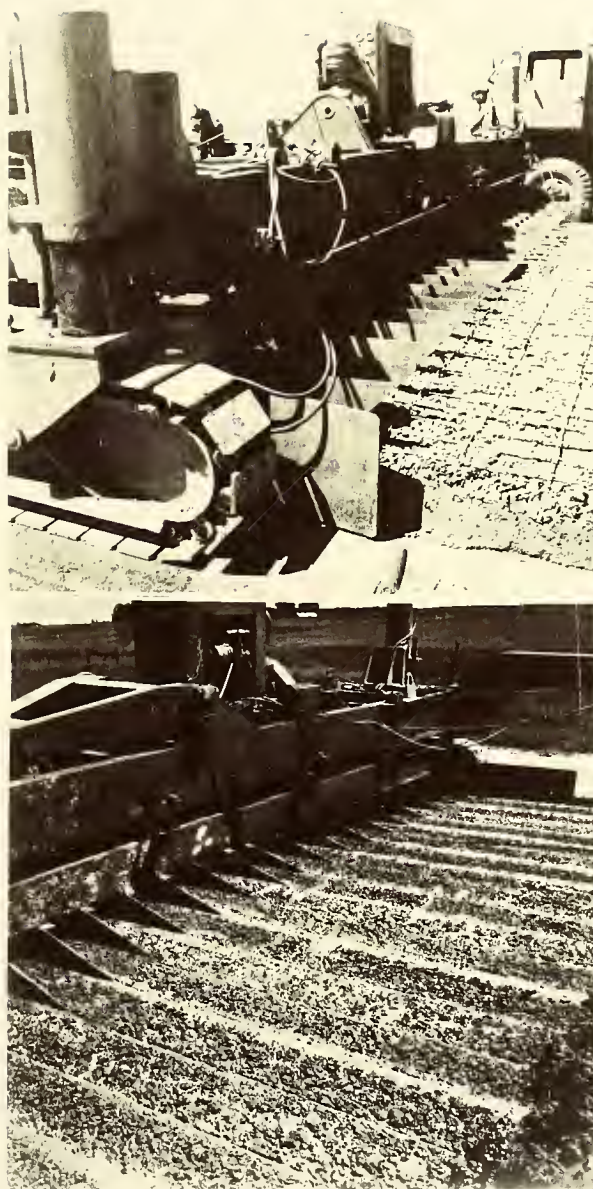


Figure 39

Front and Rear Views of a Rex Mesh Depressor

concrete. The manufacturer claims that vibration aids in blending and consolidating the mix.

The machine rides on pneumatic tires and is hydraulically powered from the slipform control. It is equipped with sideforms to keep the mix within the pavement boundaries as the steel is being depressed. A unit of this type was used for CRC paving on an Indiana section of US 41 during the summer of 1970 (see Figure 40).

Commentary

Two of the three mesh depressors now on the market use vibration and pressure, while the third uses an oscillatory motion - a gentle form of vibration - to depress the steel. Although highway officials have been somewhat concerned about the possibility of aggregate segregation from the use of vibration equipment, core tests have shown that such segregation does not occur (see Figure 38). However, further research is necessary to discover the effect which vibration has on the proper consolidation of concrete. Particular attention should be directed to the ways in which vibrators are presently used in conjunction with slipformers.

A factor contributing to the concern of responsible officials was the failure of a slab in Illinois which was constructed with the use of a mesh depressor. However, subsequent investigations showed that there was improper lap at the places where the failures occurred. This could have been the fault of workers who did not measure proper laps at the time the steel was being placed.



Figure 40

Front and Rear Views of a CMI Mesh Depressor

As a mesh depressor advances, it has a tendency to draw the steel forward. Rex Chainbelt, Inc., claims to have eliminated this undesirable feature by designing its machine to depress on the backward stroke of the oscillatory motion. This tends to tuck the mesh in place, rather than draw it forward. The Heltzel Company also claims to have eliminated any tendency to drag the steel forward, since its unit stands in position before depressing the steel. CMI claims that its machine merely produces a slight displacement of the aggregate, and the mesh just slides down to its position. It would appear prudent for highway officials to satisfy themselves, through inspection of operating units, of the validity of these and other claims made by the manufacturers.

Mechanical Methods of Placing Reinforcing Bars

Bar Placing Equipment

With bar mats and mesh, most of the labor is carried out in the shop and relatively few men are required in the field. However, with reinforcing bars, labor is required to load and unload the steel, distribute it, and lap, and tie it. Contractors have therefore developed machines which help speed the lapping and tying, as shown in Figure 41. Today, laying 4000 to 6000 ft of steel per crew day is becoming common place.

Contractors have also developed machines which, once the steel has been tied, will hold it in the desired position for

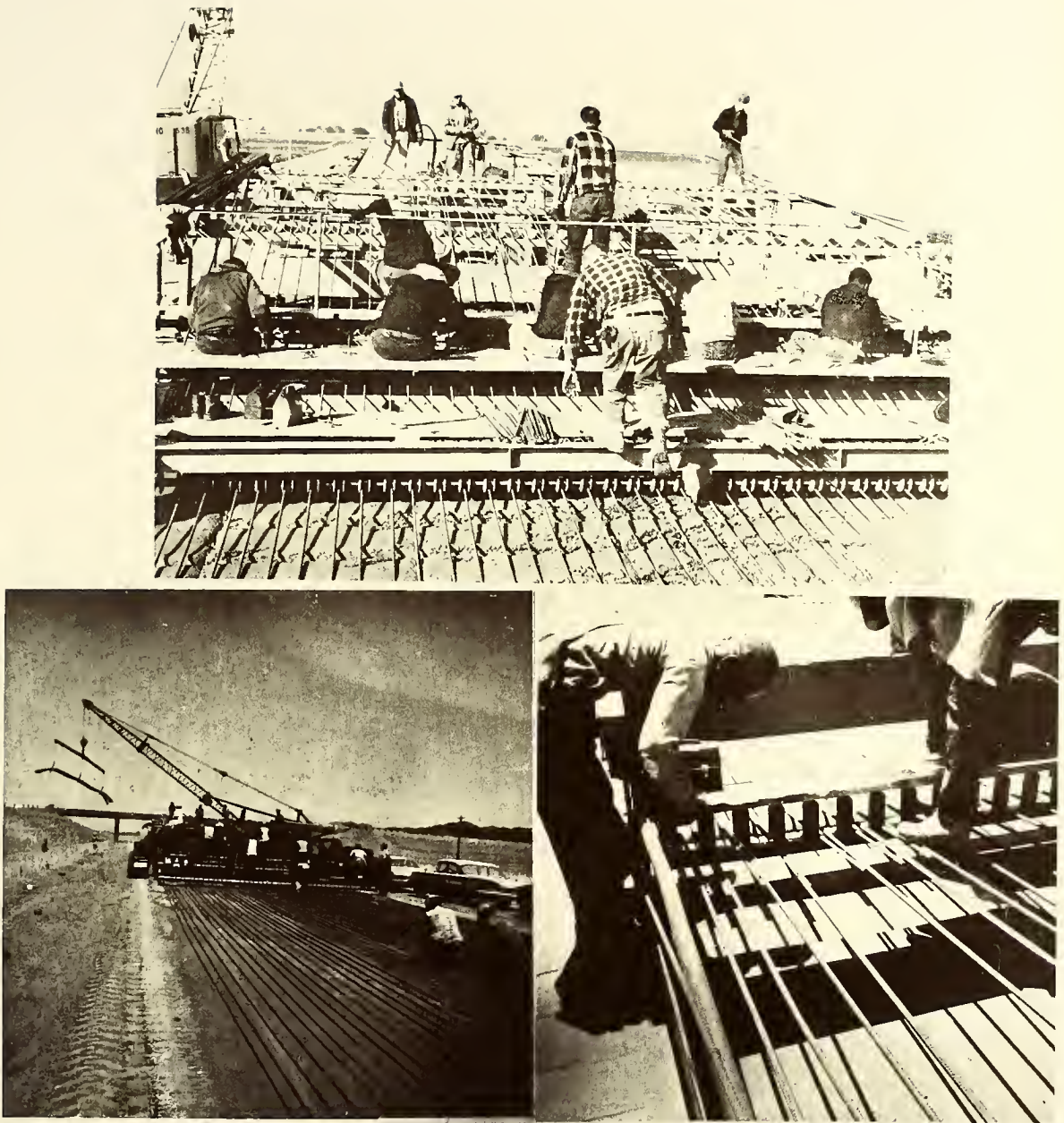


Figure 41

Jumbo Satellite Machine
Helps Speed Steel Lapping and Tying Operation

pavement construction. This position can either be its final one, in which case the concrete is placed through and around the steel; or the steel can be placed on the surface of the fresh concrete and then depressed to its final position. The three steel-placing machines which will be described herein have been used with CRC paving. The last two of them have also been used with CRC slipform paving.

Bar Vibrator

In 1964 two Illinois contractors worked together to place record daily footages of CRC pavement. They employed a steel-placing method which eliminated chair supports and permitted single lift paving (5). The contractors used two machines. The first was a 45 ft long form riding platform which travelled behind a concrete spreader. This unit was manned by workers who took bundles of 30 ft long bars from delivery cranes and strung them out in position, spliced and wire tied them, and fed the bar lines into a set of spacing cups (see Figure 41). The steel drew itself off as the rig advanced. The transverse bars were placed on 25 ins. centers by two reels mounted in front of the machine. The transverse bars were underneath the longitudinal bars. A similar machine was used by Western Contracting during the summer of 1970 on a paving job near Council Bluffs, Iowa. This machine was modified to facilitate its use in slipform paving, with transverse bars eliminated (see Job 1 on page 172).

The second machine, which performed the actual depressing, was of the general pattern used by the Traylor Brothers in Indiana in 1962, and described earlier herein. The Parro-Green construction machine consisted of two 12 x 15 ft assemblies of large vibrating grids. After it was moved into position over the slab, a hydraulic ram depressed the steel for a 15 ft length of slab. Grooved surfaces distributed the ram pressure over the steel and ensured its even submergence without local distortion or major disturbance of the fresh concrete. See Figure 42.

The steel was placed by this equipment to the satisfaction of the highway officials of the State of Illinois, being within the $\pm 1/2$ in. tolerance set by the state. The success of the method depended on the use of low slump concrete, which is also required for slipform paving. However, since this steel placing unit cannot be used with slipform paving, it is gradually becoming obsolete. This dismal future notwithstanding, the bar vibrator was a forerunner for some of the machines that have since been developed.

Tube Assembly

This is a contractor-built machine for the mechanical placing of reinforcement, and was first used in Iowa in 1966 (64). Its principle is one of holding the reinforcement in position while the concrete is deposited, spread and consolidated (6). The unit consists of a form riding frame

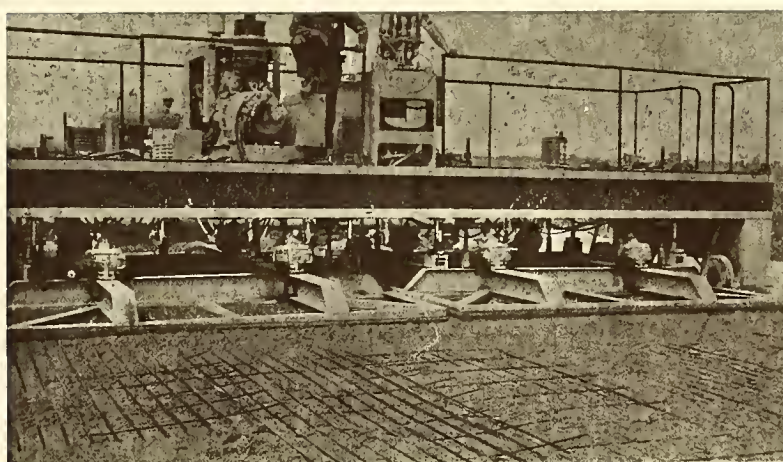


Figure 42

Bar Vibrator Machine

(Notice the similarity to Figure 36)

which contains flared tubes for receiving and positioning steel just ahead of the concrete spreader.

Two modifications of this machine are currently in use. In one of these, 44 or 48 lines of reinforcement are fed through tubes (Figure 43). In the second type, the middle six bars are not positioned but are supported with tie bars on chairs (Figure 44). The first type has recessed tubes as shown, whereas the second type has all the tubes of equal length. These design modifications do not seem to affect the ability and the capability of the equipment in any way.

The first step in the paving operation is to lay the steel reinforcement out on the subgrade, lapped and tied. The steel is then fed individually through the flared tubes which are 16- to 30-ft in length and 44 or 48 in number, depending on the design spacing of longitudinal bars. The outside diameter of the flares is about 3 in. and the inside diameter of the tubes is 2-1/2 ins. After bar feeding, the unit is attached to the front of a concrete placer where it is held at proper elevation while the concrete is placed and consolidated (Figure 45).

The tubes' height can be adjusted with the aid of double nuts and bolts located at the top of the attaching beam in the rear; another set of double nuts at the bottom can be used to adjust the tubes horizontally. The unit itself is controlled from the operator's console. One unit now in use has hydraulic cylinders at each corner to control

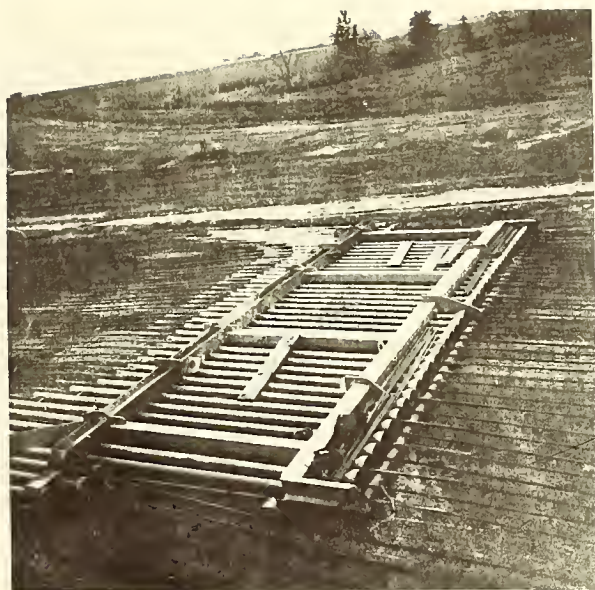


Figure 43

First Type of Tube Assembly

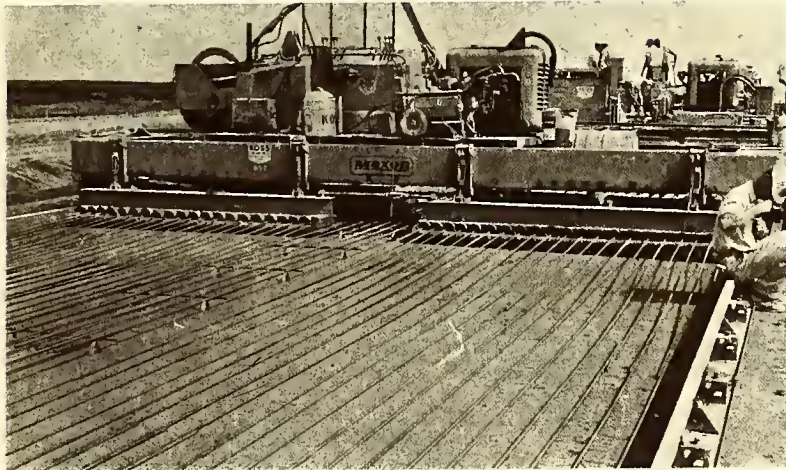


Figure 44

Second Type of Tube Assembly

(Notice that the middle 6 bars are supported on chairs)

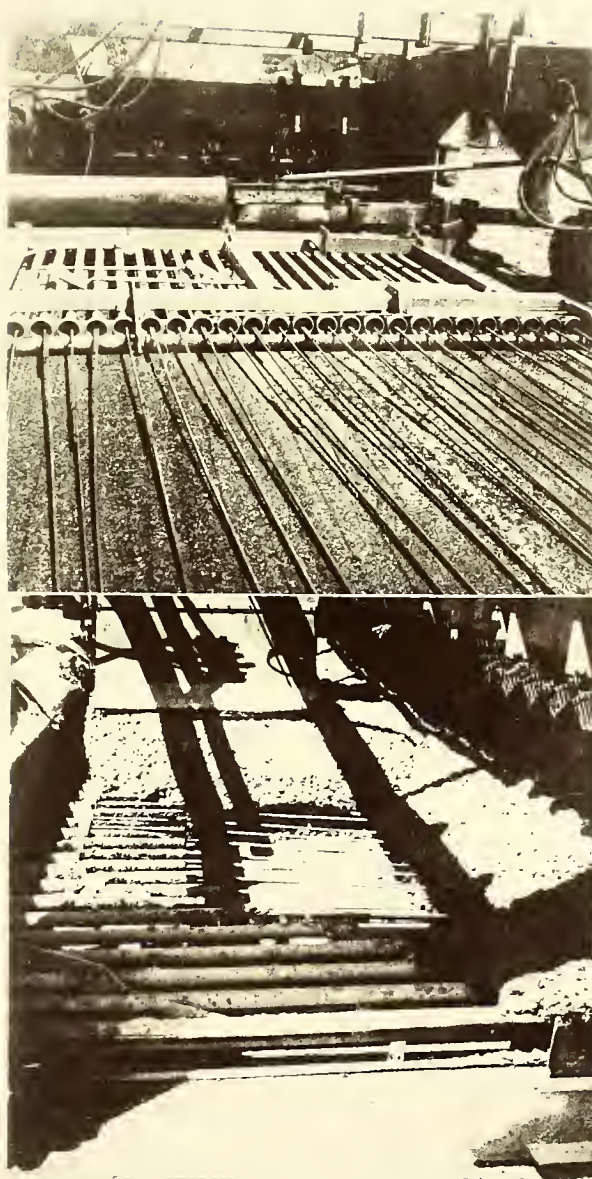


Figure 45

Tube Assembly Holds the Steel in Place
as the Concrete is Placed, Spread and Consolidated

the height. The frame holding the tubes is hinged on the bottom at the center line of the roadway with a hydraulic cylinder on top of this hinged point. This center cylinder will raise the tubes to the desired straight line crown. Tie bars, depending on their position, can be inserted by hand or by a rotating notched drum at the back of the placer. They can also be supported on chairs.

This machine has been used extensively throughout the country, including the states of Wisconsin, North Dakota, Minnesota, Virginia, North Carolina, Iowa and Illinois. In all known cases, the method was satisfactory to the state officials and no failure has been experienced yet. The machine is simple in construction and easy to use. It requires about 20 to 25 men to place the steel, which is about half the crew required to place steel by chair supports. Because of this drastic reduction in manpower requirement, reductions of between \$0.15 and \$0.20 per square yard in bid prices have been realized by states in which this method has been used.

Maximum steel-placing tolerances of about $\pm 1/4$ in., which are usually specified by some states, cannot be always met by this method. Recognizing this, some contractors have devised further attachments to the front of the slipform paver to help in depressing the steel to the precise height desired. One such device, illustrated in Figure 46, was used in Illinois during the summer of 1970. This attachment



Figure 46

Auxiliary Equipment Used with Tube Assembly

spans the width of the slab, with helical blades converging at the center of the slab to prevent concrete from spilling to the sides. The rebar installer which is described in the next section may also be used in conjunction with the tube assembly equipment.

Rebar Installer

In the summer of 1969, Rex Chainbelt Company first offered equipment for depressing continuous reinforcing bars from the surface of the full depth slab to the desired depth below the surface. The machine is designed to be compatible with Rex's belt placer but it can be used with slipform pavers. It consists of four drums on each of which is mounted a set of helical rows of teeth like those on mower sickle bar (65). These drums span the entire width of the slab and are mechanically operated. They are designed to slowly rotate, while simultaneously tamping the individual bars gradually downward to the desired position. The drums operate independently of each other and are hydraulically controlled from the slipform console.

The paving operation is started by laying, lapping and tieing continuous lengths of reinforcing rods on the subgrade. There is no need to accurately line up these rods. The steel is then raised above the subgrade by a roller in front of the spreader, and threaded through the belt placer in two separate sets (see Figure 47). The steel goes over the belt in the spreader and out through the back. A

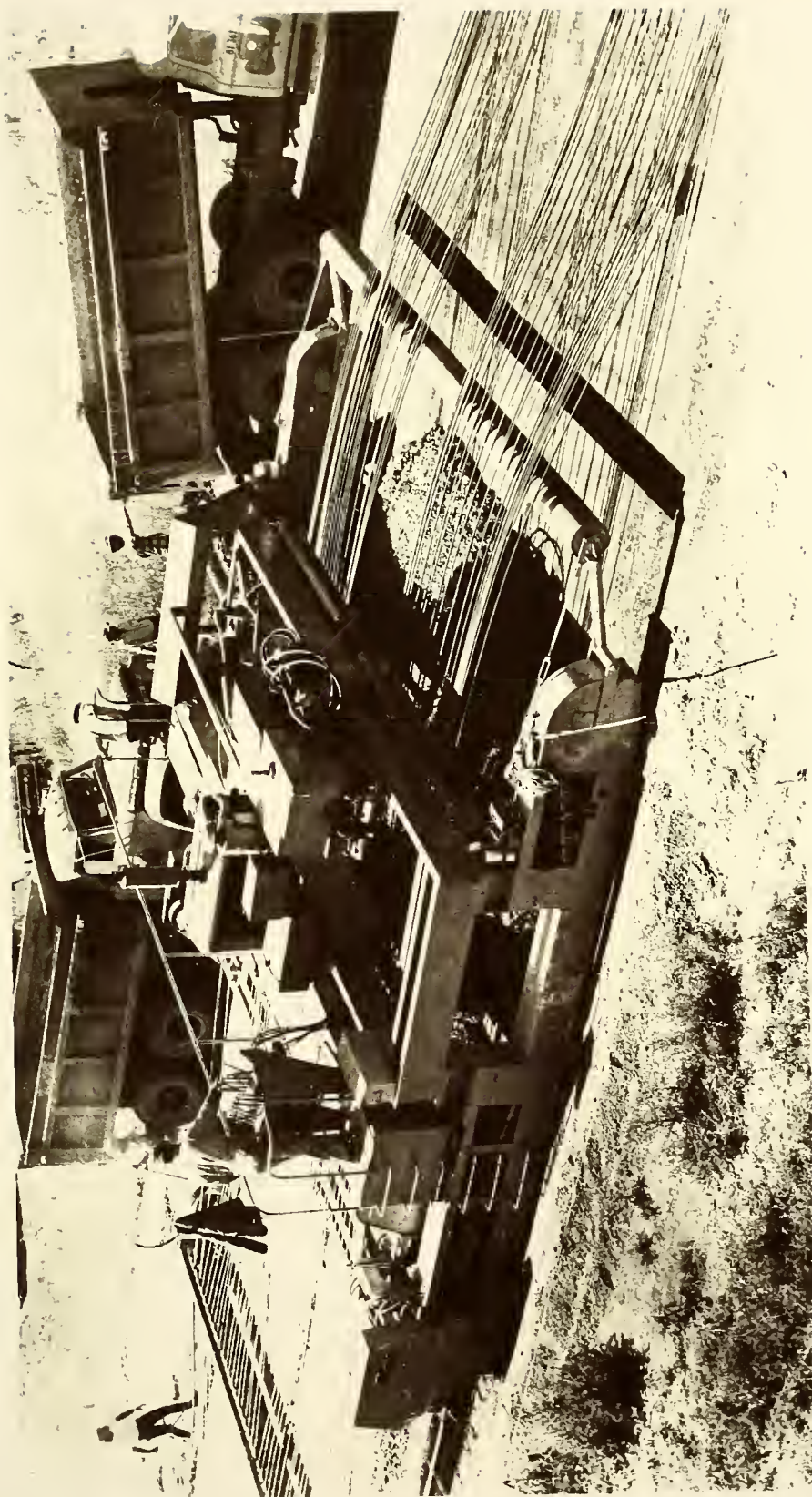


Figure 47

A Roller Raises the Steel Above the Subgrade

rubber tired unit attached to the trailing forms of the spreader brings the two sets of steel together and roughly spaces them across the width of the pavements. This unit has two horizontal pipes between which is a series of short vertical rollers spaced either at 6 or 6-1/2 ins. depending on the number of lines of steel bars, usually 44 or 48 lines. The rods are fed through these rollers for proper spacing (see Figure 48).

Another spacing unit is attached to the slipform paver, and is similar in design to the other spacer. Here all the bars are properly spaced and held in position by the set of vertical rollers (see Figure 49). This is followed by the track-mounted, saw-toothed rotary tampers attached to the front of the slipform paver. As the machine advances, the drums revolve and the serrations slip over the rods and force them down into fresh concrete (66). See Figure 50. The slipform paver completes the slab forming operation. Figure 51 shows the actual paving train as used in Iowa during the summer of 1970. Since the rebar installer is attached to a slipform paver and takes its grade from the paver wires, it installs the steel precisely to the desired elevation. The rebar installer equipment was used in Iowa and North Dakota during the 1969 and 1970 construction season and has been quite satisfactory to the state officials of these two states. The effectiveness of the method has been supported by the results of core tests and by actual digging to the steel, as shown in Figures 52 and 53 and

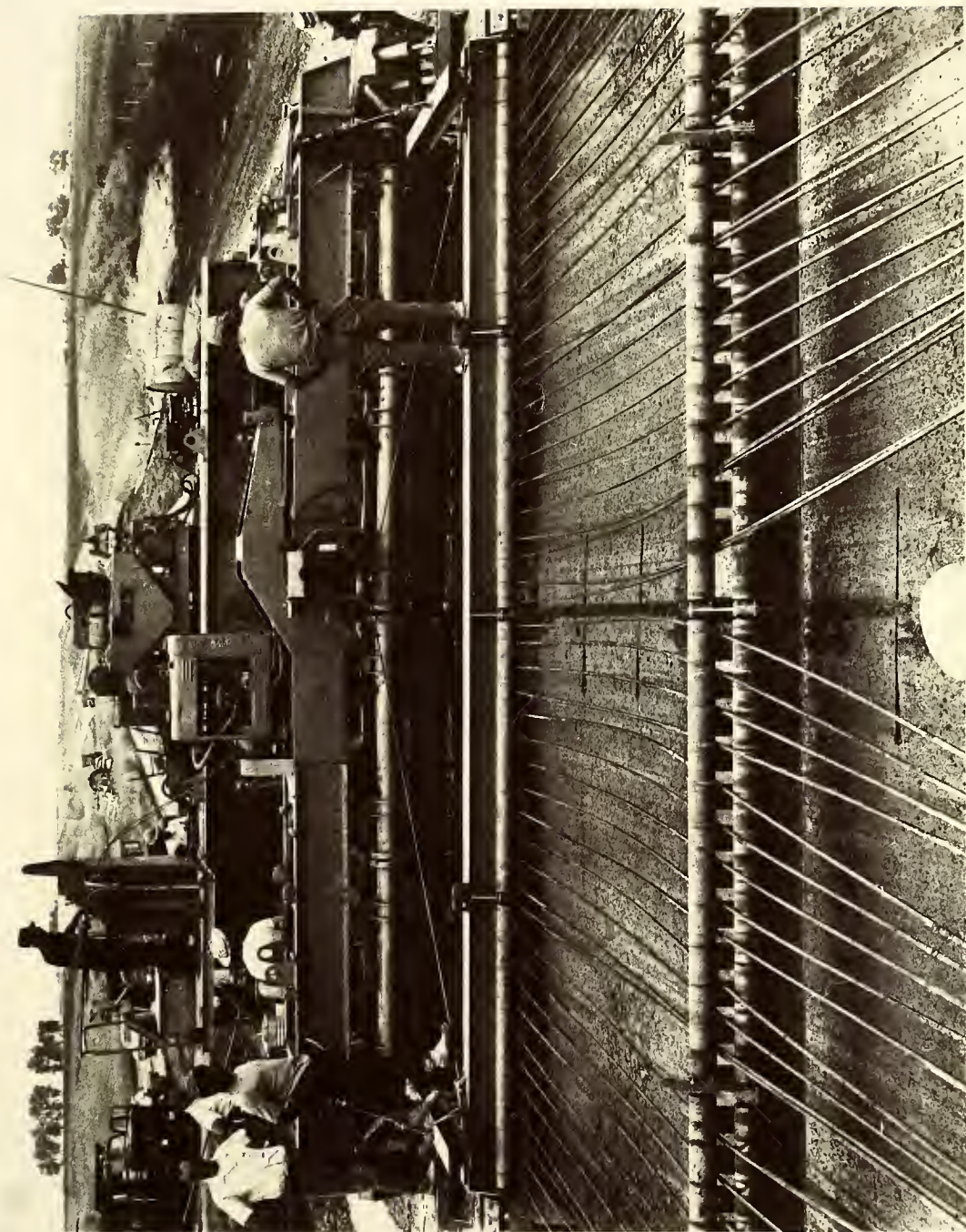


Figure 48

A Bar Spacer Attached to the Placer Roughly Spaces the Bars



Figure 49

A Second Bar Spacer Attached to the Slipform Paver
Finally Correctly Spaces the Bars

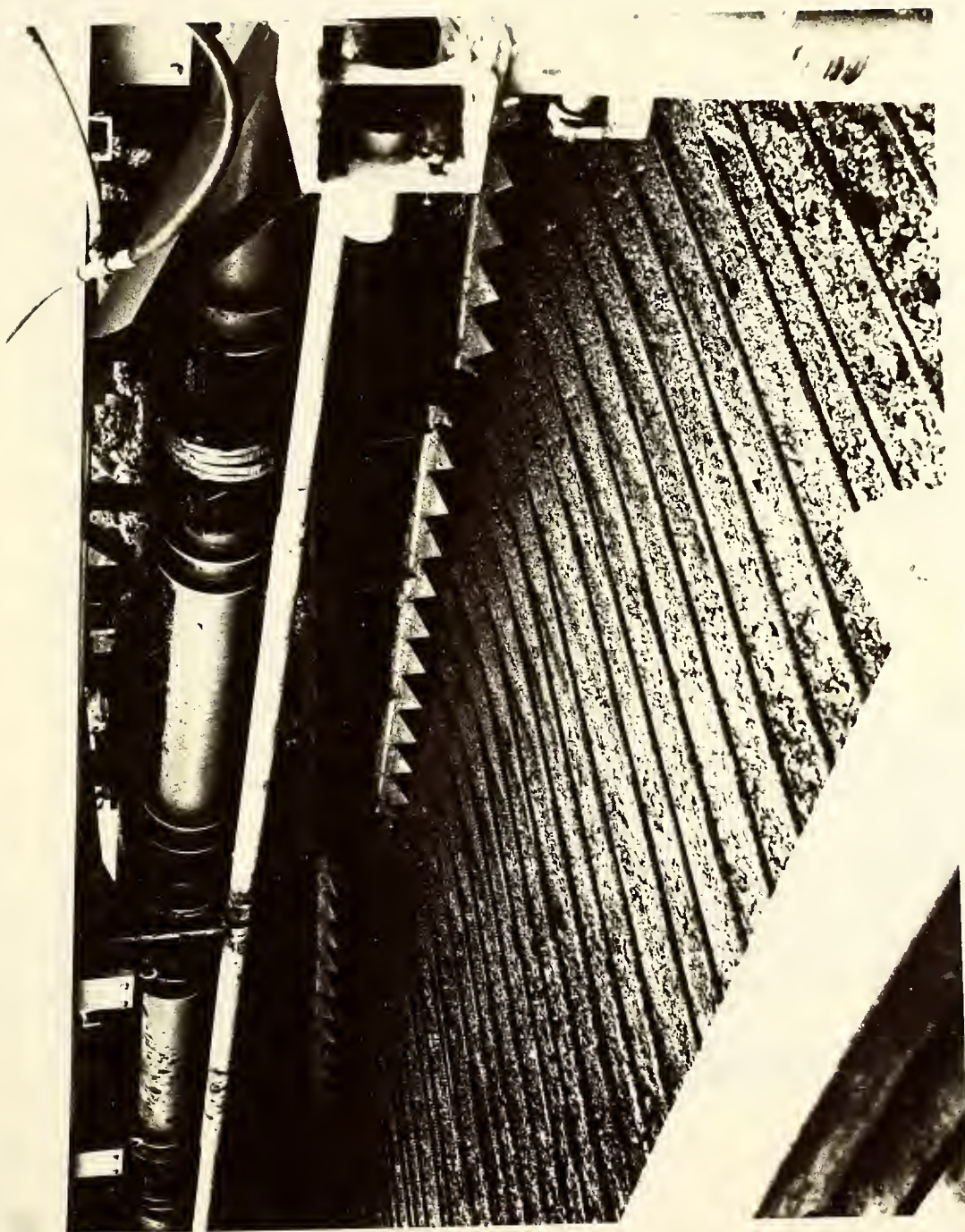


Figure 50

The Serrated Device Tamps and Depresses the Steel to Position

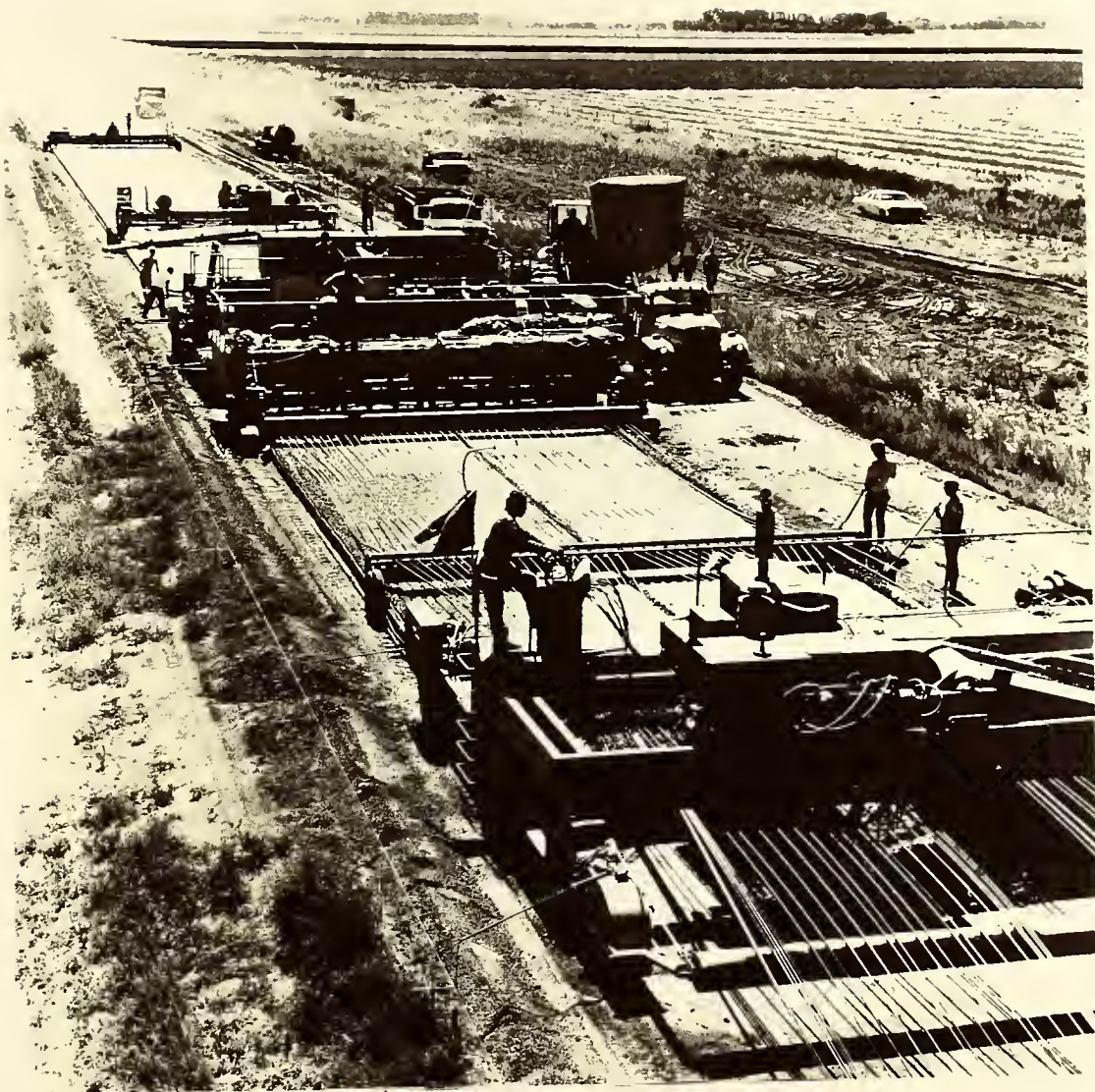


Figure 51

The Complete Paving Train



Figure 52

Checking the Position of Steel Installed by a Rebar Installer
(A state highway official displays the tools used to make the

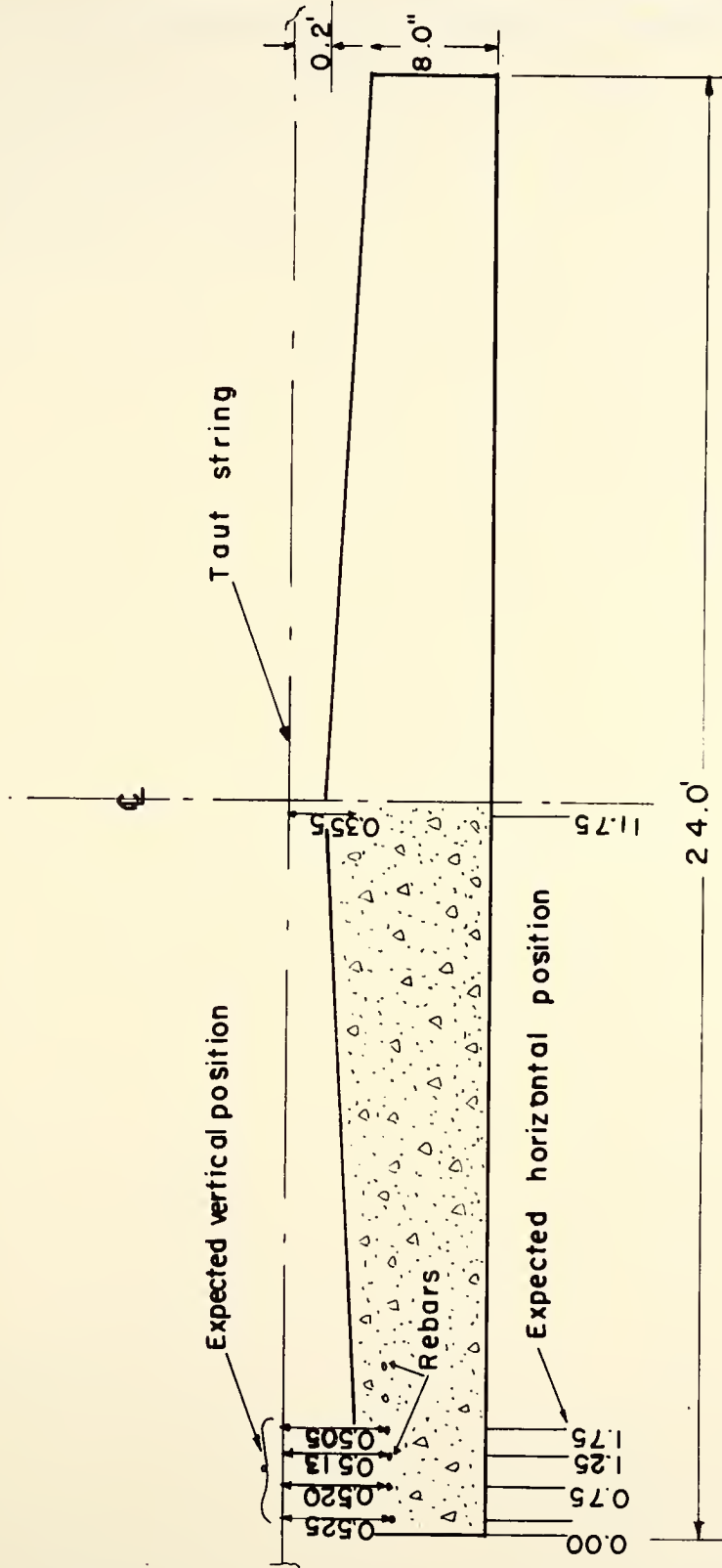


Figure 53

Cross Section of Slab Showing How Steel Position is Checked

Table 2. The method requires about 20 men for the total steel placing operation. Transverse steel is normally eliminated, although this unit can be rigged for transverse steel placement if desired.

States' Acceptance of Mechanical
Steel Placing Methods

As a part of this study, a questionnaire was sent to 15 selected states to explore their acceptance of mechanical steel placing methods. Only one state, North Carolina, did not reply to the questionnaire. The 14 states that replied were Virginia, Illinois, Maryland, Iowa, Ohio, Minnesota, North Dakota, Connecticut, California, Pennsylvania, New York, Wisconsin, Michigan and Kentucky. Of these, New York has not placed any CRC pavement and California uses no steel in its pavements. The following questions were asked concerning the mesh depressor, the tube assembly, and the rebar installer:

Question 1. Has your state used any of the methods mentioned above...? Which method(s) has it used? Has this method proved satisfactory?

Response: Only one state, Iowa, has used the three methods. One state has used both the tube assembly and the rebar installer, 8 states have used one of the other types of equipment, and two states have used none.

Table 2. Expected and Actual Position of Steel
Installed with a Rebar Installer

| Expected | | Actual | | | |
|----------------------|------------------------|----------------------|------------------------|----------------------|------------------------|
| Vertical Position | Horizontal Position | Vertical Position | Horizontal Position | Vertical Position | Horizontal Position |
| 0.525 | 0.25 | 0.53 | 0.22 | 0.54 | 0.30 |
| 0.520 | 0.75 | 0.52 | 0.69 | 0.52 | 0.73 |
| 0.513 | 1.25 | 0.51 | 1.24 | 0.53 | 1.32 |
| 0.505 | 1.75 | 0.51 | 1.84 | 0.53 | 1.84 |
| 0.498 | 2.25 | 0.50 | 2.31 | 0.51 | 2.35 |
| 0.490 | 2.75 | 0.51 | 2.84 | 0.52 | 2.83 |
| 0.483 | 3.25 | 0.50 | 3.36 | 0.52 | 3.36 |
| 0.475 | 3.75 | 0.49 | 3.82 | 0.51 | 3.81 |
| 0.468 | 4.25 | 0.49 | 4.32 | 0.51 | 4.31 |
| 0.460 | 4.75 | 0.48 | 4.85 | 0.50 | 4.81 |
| 0.453 | 5.25 | 0.49 | 5.34 | 0.50 | 5.32 |
| 0.445 | 5.75 | 0.50 | 5.80 | 0.50 | 5.78 |
| 0.438 | 6.25 | 0.49 | 6.31 | 0.48 | 6.31 |
| 0.430 | 6.75 | 0.49 | 6.80 | 0.45 | 6.78 |
| 0.423 | 7.25 | 0.46 | 7.27 | 0.44 | 7.32 |
| 0.415 | 7.75 | 0.45 | 7.80 | 0.44 | 7.85 |
| 0.408 | 8.25 | 0.45 | 8.29 | 0.43 | 8.31 |
| 0.400 | 8.75 | 0.43 | 8.78 | 0.41 | 8.81 |
| 0.393 | 9.25 | 0.41 | 9.30 | 0.39 | 9.31 |
| 0.385 | 9.75 | 0.41 | 9.78 | 0.38 | 9.76 |
| 0.378 | 10.25 | 0.41 | 10.30 | 0.38 | 10.28 |
| 0.370 | 10.75 | 0.40 | 10.80 | 0.37 | 10.80 |
| 0.363 | 11.25 | 0.40 | 11.30 | 0.36 | 11.32 |
| 0.355 | 11.75 | 0.39 | 11.79 | 0.36 | 11.82 |

Five states have used the mesh depressor, 3 states have used the rebar installer and 3 have used the tube assembly. These responses do not include methods that were tried for the first time in the summer of 1970. All the states reported satisfaction with the methods that they had tried.

Question 2a. Some states have found it necessary to change the specification for steel tolerance in order to accommodate these new methods. Did your state make such changes?

b. What was the old specification?

c. What is the new one?

Response: Five states have revised their specifications to accommodate the new techniques. These revisions varied from 2-1/2 ins. below the slab surface to mid-depth, with about 1 in. lateral displacement. Some states such as Ohio, Iowa, Kentucky, and Connecticut already have specifications with large tolerances which the machines have had no problems in meeting.

Question 3a. Have there been any failures in pavement slabs associated with the above methods?

- b. What were these failures attributed to, e.g. bond failure, air pockets around steel, etc.?

Response: No failures have been experienced yet with any pavement placed by any of the above methods.

Question 4a. Some states have eliminated the use of transverse steel when the longitudinal steel is well held in place. Does your state use this practice?

- b. Have there been any failures such as longitudinal cracks or any other bad effects attributed to this practice? Please explain.

- c. How much saving per square yard do you believe can be realized from such an elimination?

Response: Four states have eliminated transverse steel and none has experienced any failures so far from such elimination; Maryland has approved the move, but has yet to use it. The remaining states still use transverse bars. So far around the nation, 6 states have eliminated transverse bars and many more are considering the move (55). It was estimated that as much as \$0.15 to \$0.50 can be

saved per square yard, depending on the cost of material and labor, when transverse reinforcement is omitted.

Question 5. How much saving per square yard do you believe the state has realized from the use of machines to place reinforcing steel instead of by hand labor? Please specify, if you can, how much is realized by each type of equipment you have tried.

Response: One state gave an estimate of \$0.10 saving. All the other states did not supply any information in answer to this question.

Question 6. Some states have experienced failures from the use of the mesh depressor with CRC pavements. Do you know of any states who have had failures from the use of this machine?

Response: The states that have used the mesh depressor with CRC pavement have had no failures. The failure in Illinois was unique and was attributed to improper lap and depth. A pavement constructed four years ago in Connecticut is still in good condition and trouble free too!

A summary of the responses by individual states now follows in Table 3.

Table 3. States' Responses to Questionnaire

| STATE | QUESTIONS 2 AND 3 | | | | | | | | | | |
|----------------|-------------------|---|--|-----|-----|--|---------------------------|------------------------------|--|--------------------------------------|--------------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| | Mesh (a) | Tube Depressor Assembly (b) | Rebar Installer (c) | (a) | (b) | (c) | (a) | (b) | (c) | (a) | (b) (c) |
| California | | No Steel With Portland Cement Pavements | | | | | | | | | |
| Connecticut | Yes | X | - | Yes | Yes | Steel installation is now covered by special provisions. | No | - | No | Limited Experience No estimate | No Knowledge |
| Illinois | Yes | X | Tried in Summer of 1970. See Job 7. | Yes | Yes | + 1/2" | Yes | Improper Lap and Depth | No | estimate Yes | No Comment |
| Iowa | Yes | X | X | Yes | No | See note 1/ | No | - | Not Available | - | No Knowledge |
| Kentucky | No | Experimental CRC constructed with chair supports. | - | No | No | See note 1/ | No | - | - | - | No Knowledge |
| Maryland | No | Experimental CRC constructed with chair supports. | - | No | No | - | No | - | Note 2/ \$0.25 to \$0.30 Experience psy. | No | No Knowledge |
| Michigan | No | X | - | - | Yes | 2-1/2" + 1/2" min. mid-depth | See 2/ Note 3/ Bond | Improper | No | No | No Knowledge |
| Minnesota | No | - | - | - | No | 2" to 4" below surface | - | - | \$0.10 to \$0.15 Experience psy. | No | No Knowledge |
| New York | | No CRC Pavement Built to Date | | | | | | | | | |
| North Carolina | | No Response | | | | | | | | | |
| North Dakota | Yes | - | X | Yes | Yes | + 1/2" from 1/2" above mid depth. | No | - | Yes | No \$0.25 psy. | No Knowledge |
| Ohio | Yes | X | - | Yes | Yes | See note 1/ 2" to 2-1/2" 3" + 1/2" below surface | No | - | No | Estimate | No Knowledge |
| Pennsylvania | No | - | - | - | - | - | - | - | No | - | No Knowledge |
| Virginia | Yes | - | X | Yes | Yes | 3-3/4" + 1/4" 3-1/2" + 1/2" | No | - | Yes | No Savings Estimate | No Knowledge |
| Wisconsin | Yes | - | X | Yes | No | 2" + 1/2" below surface | No | - | Yes | No Data Infor- mation | No Knowledge |

Note: Ohio and Connecticut both use 3" + 1/2". Kentucky's new specification will read 3" + 1/2" to the top of steel instead of to the middle. Iowa's specification of 2-1/2" min. cover and 4' min. bottom clearance and 1" lateral displacement is not changed.

Note 2/: Practice has been approved but has not been used to date.

Note 3/: Experienced failures with two-course method. The state now requires steel to be installed by one lift with the option of chairs or mesh depressor. Contractors have continuously elect mesh depressor.

PART III
CASE STUDIES

PART III - CASE STUDIES

Objectives and Scope

The objectives of each case study were to obtain a permanent record of the steel placement method, to determine the labor requirements for placing reinforcing steel in CRC pavements, and to examine the possibility of simplifying each operation or reducing the amount of labor and the number of cycles involved with each operation.

Eight jobs were studied, five with deformed bars and three with mesh. Attention was directed to the methods for laying steel and placing concrete. The three mesh jobs were depressed with the three types of mesh depressors described in Part II, each job with a different type. The five jobs with bars used various methods for steel placement. On one job, the steel was installed on chairs by use of a self-propelled unit. Two jobs used the rebar installer only, one used a combination of rebar installer and tube assembly, and the last one used tube assembly only. All but one of the pavements were constructed with slipform pavers. No basis for judging relative performance was established, other than the merits of the methods in themselves.

All but one of the jobs studied were on interstate highway systems. Six of the contractors were contacted ahead of time, while the other two were informed of the studies on their sites of work. All the contractors offered excellent cooperation.

The studies took place in Iowa, North Dakota, Minnesota, Illinois and Indiana. Those in Indiana involved the use of two mesh depressors. One Heltzel mesh depressor, which rode on forms, was used for CRC paving on I-69 near Indianapolis; and a CMI mesh depressor was used on US 41 near Boswell for experimental purposes.

Techniques Employed

Two methods were used to gather the field data, namely interviews and observations.

Interviews were conducted with paving foremen, steel foremen, and/or local or, state officials, depending on who was available. Questions were asked concerning the job and steel specifications, the methods of hauling and placing steel, the labor involved in steel placement, paving length per day, methods of concrete production and placement, and the experiences in the use of the technique for placing steel. Supplementary comments about the equipment and relevant matters were also noted.

The work method was recorded by time lapse photography. This has been found to be an inexpensive method for recording construction activities. The time lapse movie camera used

in the observation was preset to take a frame every three seconds. In some instances, additional records were taken at 16 frames per second to better portray the operation of a particular piece of equipment. Important features were also photographed with an ordinary camera, and some of these pictures are included in this report.

A full description of time lapse photography equipment and its construction application is supplied elsewhere (67) and will not be repeated here. However, the application of the method in these studies will be briefly summarized in the following paragraphs.

Selection of Jobs

The study objectives did not include a statistical analysis of job parameters, and the jobs were selected without regard for possible statistical bias. The eight jobs were chosen on the basis of consultation with state officials and other persons. The contractors involved in six of the jobs were contacted in advance and told about the planned study. After obtaining their tentative paving schedules, a preliminary program of field observations was prepared. The six contractors were then notified of this program and the necessary final arrangements were made.

The remaining two jobs were brought to the attention of the author during a visit to the site of Schultz and Lindsay in North Dakota. The jobs were those of Woodrich and Central State Construction companies. Both jobs were in Minnesota.

The contractors were contacted on their sites of operation and gave permission for the studies to be performed.

Time Lapse Photography

A permanent record of each method of steel installation was desired. This record could then be used to identify the labor requirements for each steel placing operation and to explore the feasibility of simplifying the methods of performing the work. Previous studies had indicated that time lapse photography provided an efficient method of recording construction operations (67). Accordingly, the technique was applied to these studies. Some modifications were necessary in order to obtain full views of the constantly-moving area of work operations.

Planning the Study

When planning a study of work methods, a construction manager will normally choose an operation where costs are high or are difficult to control. A major interest in the research reported herein was to find less expensive ways than chair supports to place reinforcing steel in CRC pavements. It was therefore logical to select the steel placement operation for detailed study. This operation generally involves stockpiling the bars in a storage yard during winter and bringing the bars to site as needed in summer. The steel is carried to its position by laborers (or by steel setters, if required by the Union) then positioned, lapped and tied. Finally, when slipform paving

is employed, the steel is either fed through one of several devices described in Part II, or it is supported on chairs.

Time Lapse Equipment

The equipment used in this study included a 16mm Kodak K-100 movie camera equipped with a zoom lens attachment and a view finder which showed the picture as it would appear on the finished film. The film used was Kodachrome II daylight color. Other items of equipment included a battery-powered mechanical timer to regulate the camera; a small 24 volt constant speed motor to drive a cam and thereby actuate two micro-switches on a solenoid linked directly with the camera; a power pack consisting of 4 dry cell batteries to provide power for the system; a digital counter to register the number of exposed frames of film; and a lightmeter to measure the correct length of exposure for the lighting conditions. A Kodak Analyst movie projector was modified to permit either forward or reverse operation at speeds as slow as 6 frames per second. This projector was also equipped with an interval button which could be used to hold a frame and to project one frame at a time during analysis. Figure 54 shows the time lapse equipment as used in this research.

Procedure for Operation

On the site of operation, it would be desirable to position the camera so that all of the work force could be photographed together. This requirement could not be met on several of the paving jobs which were studied. The continuous

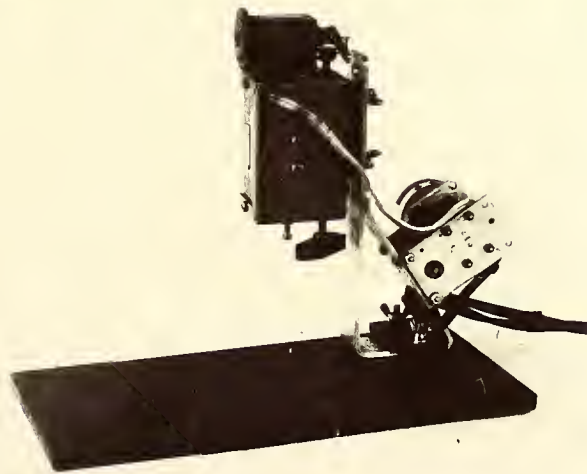


Figure 54

Time Lapse Photography Equipment

intermingling of equipment and personnel also made it difficult to identify a repetitive working cycle. However, the major problem was the rapid movement of most of the operations. Before the equipment could be set up and an adequate number of pictures taken for subsequent analysis, the paving equipment had moved so far as to distort the field of view for the camera. Therefore, on first reaching a study site, significant time was spent in trying to locate the best position for the photographic equipment. This position would usually be several feet away from the paving operation, possibly on the lanes opposite to the one being paved. Sometimes the best position would be on a frontage road which was completely removed from the construction area. It was found that the best way to obtain a good view was to set up the camera on top of a car and be about 500 ft away from the operation (see Figure 55).

After the location had been selected and the camera with all of its attachments had been set up on the car, the exposure meter was used to determine the appropriate f-stop. This f-stop was then set on the camera and, by using the view finder, the operation was located. The zoom lens attachment was then used to bring the operation as close as possible. After these preliminaries, the solenoid was activated and the operation was recorded. It was necessary to make frequent focusing and f-stop adjustments as the paving operations moved closer or as the lighting condition changed.



Figure 55

The Best Position Was on Top of a Car
and About 500 ft. Away From the Operation

"unproductive". A similar reasoning was applied to the use of equipment.

It was extremely difficult to classify the time involved in moving equipment to a new position (MTNP). Primarily for uniformity, MTNP was classified as "unproductive" through out all analyses.

When the workers performed in the same individually identifiable groups, the group was analyzed as a unit. However, when the composition of a group continually changed, the workers were analyzed individually.

The classification for each work element will now be supplied. Most of these classifications are self explanatory, but supplementary notes are included for selected items.

Productive Items

1. Sort Steel: The worker sorts the steel from the stockpile.
2. Carry Steel: Steel is carried to position; applies to both mobile crane and workers.
3. Position Steel:
4. Return to Stockpile:
5. Load Steel: The mobile crane is loaded
6. Hook Wires to Steel: Workers use wires to hold a bundle of steel together before the crane picks it up.
7. Set Template: Workers set a template which is used to gauge the proper lap for steel.

The procedure just described was repeated for each of the cases studied. The photographic observations included the methods for initial steel placement and for final positioning of the steel. Each steel placement operation was recorded for at least one hour. The average observation time for the complete steel installation was about 2-1/2 hours.

Method of Analysis

The analyses were the most difficult parts of the case studies. Each film was reviewed several times so that the analyst could familiarize himself with the tasks involved in each operation. This preview indicated that the initial steel placement was the only part of the complete paving cycle which could be adequately analyzed on the basis of the field records. Even this limited analysis was not possible for Job 5, where the steel placement operations were spread over an area which extended beyond the field of view of the camera. Further, since the steel crew of Job 7 did not work on the day that the site was visited, it was also necessary to eliminate this job from the analysis.

Following the selection of the initial steel placement for detailed study, a work element classification was developed. The work operations were also classified as "productive" or "unproductive". This latter classification was based on whether or not the operation resulted in an increase in the length of steel placed. An individual who was not doing what he was employed to do was classified as

8. Check Space and Hook Chair:
9. Tie Steel:
10. Lap Steel:
11. Position and Distribute Steel: Workers distribute the bars across the paving width, and position them as specified.
12. Lap and Position Steel: This combination duty is shared by the workers.
13. Unload Steel:
Unproductive Items
 1. Move to New Position: Man or machine moves from one position to another to start a new cycle of operation.
 2. Idle:
 3. Personal Time:
 4. Waiting for Another Trade: A group, an individual or a machine is delayed by another work element; for example another person, or group, or machine.
 5. Tow Machine: Applies to Job 1 only.
 6. Climb Truck:
 7. Get Off Truck:
 8. Return to Truck:
 9. Hold Cable: A worker holds the cable that is used to support steel.
 10. Support Steel: A worker holds one end of the steel load as it is being carried to the subgrade.

11. Delay: Caused by equipment breakdown or material supply.

Based upon the classifications just described, a detailed analysis was made of each method of steel placement. The time element for each activity was obtained by counting the number of film frames in which the activity in question appeared, and then multiplying this by the standard 3 second frame interval. The percentage of time spent on each operation for the period of observation was then calculated. From these percentages, conclusions could be drawn and suggestions for possible improvements in the methods could be made.

Details and Descriptions of Cases Studied

Each case report commences with a listing of key job data, as obtained from interviews with the paving foreman, steel foreman, or state officials on the job. The methods used to carry, distribute, lap and tie the steel are then described. If the analysis suggests any ways whereby these methods might be improved, the possible revision are next described. The jobs are presented in the order in which they were studied.

The job analyses presented here merely record the manner in which each contractor utilized his labor and equipment. No attempt has been made to compare the relative efficiencies of the contractors' operations. Even though some of the methods of executing the jobs were similar, the specifications

under which they were performed were different. Also, the operations could not be observed for equal lengths of time because of localized conditions which blocked the line of vision or made a suitable position inaccessible.

The percentages listed for each activity and each job element are based on the period of time within which that job element was observed. For example: assume that the reinforcing steel setters on a job were found to be positioning steel for 25% of the total time that they were observed. Assume also that the steel setters were observed on another job to be positioning steel for 40% of the total time. One cannot conclude that those two percentages reflect the fact that either group was more efficient than the other because the periods for which each group was observed were different. It was impossible to observe each group for equal periods of time because the working crews were continually advancing, and with a fixed camera set-up only one part of the job could be observed at a time. This observation also holds true for activities on the same job; that is, the percentage of time for which the steel setters were productive is not related to the percentage of time in which the steel tiers, or any other activities, were productive.

To summarize, each job element contains individuals or groups who are doing the same thing on different jobs or are doing different things on the same job. These elements were

observed for different periods of time, therefore, the composition of each element, in terms of productive and unproductive times, should be evaluated within the context of the duties that these individuals were performing. The performances of these individual activity units can then be coordinated and their effects on the overall performance of the contractor can be evaluated.

Job 1: Rebar Installer Plus Tube Assembly

Job Details

Location

I-29 South, Council Bluffs, Iowa.

Job Specifications

CRC pavement, 8" thick, 24 ft wide, 5/8" deformed bars, placed 2-1/2" - 3-3/8" below the surface with option of omitting transverse bars; 2-1/2" parabolic crown.

Steel Specifications

Longitudinal Reinforcement

| | |
|-----------------|---------------|
| Length of bars | 60' |
| Spacing of bars | 6" on centers |
| Lap | 16" |
| Lap stagger | 6' |
| Connection | Wire tied |

Placement method: Tube assembly aided by rebar installer.

Tie Bars

| | |
|---------|------|
| Length | 36" |
| Size | 1/2" |
| Spacing | 42" |

Placement method: By hand from pre-measured string behind belt placer.

Hauling and Placing of Steel

Storage Yard Equipment: One mobile crane. Steel is brought to yard by rail in winter and stored there until needed.

Hauling Equipment: One semi-truck.

Steel Placing Equipment: One mobile crane and one bar assembly rig or "Jumbo Satellite" built by contractor (see Figure 41).

Labor to Move Steel to Site:

| | | |
|----------------|---------------|---|
| | <u>Number</u> | |
| Crane operator | 1 | |
| Laborers | 3 | |
| Truck driver | <u>1</u> | |
| Sub Total | | 5 |

Labor to Lay Steel:

| | | |
|-------------------------------|----------|----|
| Rope men | 3 | |
| Oiler | 1 | |
| Crane operator | 1 | |
| Placing crew (Man 1 to Man 7) | 7 | |
| Tieing crew | 10 | |
| Foreman | <u>1</u> | |
| Sub Total | | 23 |

| | | |
|-------------|----------|-----------|
| Tiebar crew | <u>3</u> | 3 |
| Grand Total | | <u>31</u> |

Average Length of Steel Laid per 10 hr. day: 5300'.

Concrete Production: Central Plant

| | |
|--|-----------------|
| Capacity of Plant | 550 cy. yds/hr. |
| Capacity of Hauling Unit | 8 cu. yds. |
| No. of Hauling Units (depending on distance to plant) | 7-15 trucks |
| Average Quantity Placed per Day | 2500 cu. yds. |
| Average Length Paved per Day | 3600-4000' |

Description of Paving Train:

CMI Belt Spreader Placer

Western Contracting Slipform Paver (Operator experience
- 5 yrs.).

Western Contracting Burlap Machine

Western Contracting Tube Assembly attached to the front
of belt spreader.

Western Contracting Rebar Installer attached to the
front of slipform paver.

Description of Job Method

Crane loads of longitudinal bars were hauled from the storage yard by truck and stockpiled near the prepared asphalt base. They were picked up by a mobile crane, using a cradle supplied by rope men, and deposited on the Jumbo Satellite. From here the steel crew

spread the 60 ft. bars, spliced them and tied them. The self-propelled Satellite then moved forward. Six bars in the middle were then tied to the tie bars and left on the subgrade (see Figure 56).

At the beginning of the paving operation, the bars were fed through the tubes and the middle six bars were passed over a roller. There was no need to refeed bars after the operation had started on one side. The tube assembly was then attached under the spreader. Concrete was dumped on the belt spreader which distributed it across the width of the slab and around the reinforcing steel. This was followed by the rebar installer, built by the contractor and patterned after the Rex type, which tamped the steel to the correct position.

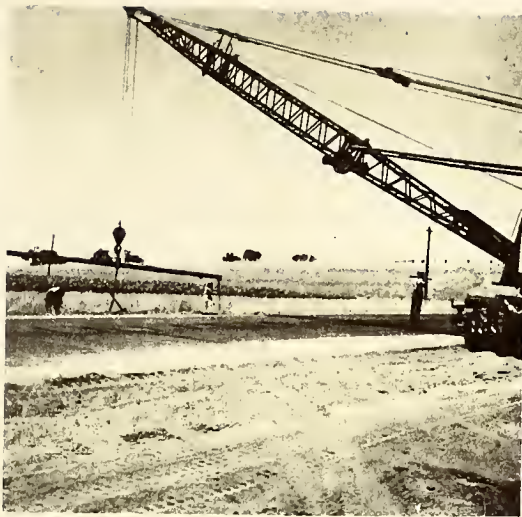
The contractor-built slipform paver, with no trailing forms, then completed the slab.

The paver was followed by a crew of two finishers, with long hand floats, who finished the slab.

The surface was burlapped by a contractor-built machine and the pavement was cured by covering with burlap.

Comments:

The contractor used the rebar installer in conjunction with the tube assembly because the tube assembly was placing the steel higher than the required 2-1/2"



1.



2.



3.



4.

Figure 56

Enumerated Procedure for Laying Steel by the Use of Jumbo Machine

1. Mobile crane with cradle carries steel from stockpile on the roadside,
2. and places it on the Jumbo Satellite where
3. it is distributed, spliced and tied.
4. The 6 bars in the middle are attached to tie bars.

below the surface. With this modification, the steel was depressed within the specified range.

This contractor had used the tube assembly before, satisfactorily.

The number of men used to place reinforcing steel was somewhat less than the 40 to 60 required with chair supports.

Analysis of Steel Placement Operation

The steel placement method used by this contractor was the most sophisticated of the several methods observed. Of the 31 men employed to lay the steel, 26 were working on or around the Jumbo Satellite machine. Seven of these men distributed the steel on top of the machine and their time utilization was analyzed in detail. It was not possible to record the productive periods for the remaining 18 men who were involved in the lapping and tying of the steel, due to limited field of view.

The general procedure for laying the steel was as follows. Steel was brought to the site and deposited on one side of the subgrade. From this position, three men called "Ropemen" would load a bundle of steel into a cradle attached to the booms of a mobile crane (see Figure 41). The mobile crane then elevated the steel and held it aloft before proceeding to deposit it onto anyone of the six stockpiles on the Jumbo Satellite machine. The crane was then supposed to return to the stockpile and start a new

cycle, but the actual working cycle for the crane was not a uniform one. Some cycles were interrupted when the crane was directed to tow the Jumbo Satellite machine, despite the fact that the Jumbo was supposed to be self-propelled. This additional assignment interfered with the steel-handling cycle time for the mobile crane.

After the mobile crane had deposited its load, seven reinforcing steel setters working in random and inconsistent groupings would then position the steel in spacing cups. After this positioning, another crew would lap and tie the steel in continuous lines. With this machine, and using 60 ft bars, the contractor was able to lay 5300 ft of 48 lines of bars in a 10 hr day. This meant that, on the average, the 30 man crew laid approximately 9 x 48 bars per hour.

When analyzing the steel placement, attention was focused on the operation of the mobile crane. This unit was always idle for some time during each of its steel positioning cycles, and it was classed as "unproductive" while it was engaged in towing the "self propelled" Jumbo Satellite machine. Attention was also focused on the seven steel placers on the Jumbo machine, since their work seemed to be delaying the cycle time of the mobile crane.

It was found that the mobile crane was stopped during almost 41% of the cycles and was used to tow the Jumbo machine for 3.5% of the time. These two operations

accounted for almost 45% of the crane's total working time. See Table 4.

In attempting to find the reason for the breaks in the continuous operation of the mobile crane, the activities of the seven reinforcing steel setters were individually analyzed to find out where the delays were occurring. These men appeared to have no defined working plan. There was no identifiable cycle of operation, and each man helped to unload steel wherever there was steel to be unloaded from the crane. Table 5 shows the distribution of the work elements as percentages of the working time. As can be seen from this table, the first two men worked as a unit with a high percentage of productive time, whereas the unit composed of the third and the seventh men was productive for a much smaller percentage of time. The remaining three men had productive time percentages which fell between the two extremes. The non-uniform utilization of equally-paid labor was apparently due to an inherent imbalance in the operation. The men on one side of the Jumbo Satellite were either idle for most of the period, or were engaged in unproductive activities.

The project manager would certainly be interested in reducing the ineffective utilization of manpower and equipment. He would seek answers as to why four or five men were needed to unload a bundle of steel which was loaded by three men; why only two men continued to work when the

Table 4. Times Spent on Various Activities by the Mobile Crane.

| | |
|----------------------------|--------------------------------------|
| Job No.: <u>1</u> | Location: <u>I-29 S. Iowa</u> |
| Contractor: <u>Western</u> | By: <u>oto</u> |
| Film No.: <u>1</u> | Date: <u>7-1-70</u> |
| Activity | Productive (%) Unproductive (%) |
| Return to Stockpile | 10.63 |
| Load Steel | 21.84 |
| Carry Steel | 8.38 |
| Stop | 40.85 |
| Start Again Carrying Steel | 10.39 |
| Position Steel | 4.37 |
| Tow Machine | <u>3.54</u> |
| % Productive | 55.61 |
| % Unproductive | <u>44.39</u> |
| Average Cycle Time (mins.) | |
| With Stops | 6.09 |
| Without Stops | 3.21 |

Table 5. Times Spent on Various Activities by Steel Setters, Job 1*

| Activity | Productive (%) | | | | | | | Unproductive (%) | | | | | | |
|------------------------------------|----------------|-------|-------|-------|-------|-------|-------|------------------|------|-------|-------|-------|-------|-------|
| | Man No. | | | | | | | Man No. | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Position Steel | 86.78 | 86.78 | 52.88 | 70.17 | 62.37 | 56.61 | 51.87 | | | | | | | |
| Unload Steel | 7.12 | 7.12 | 4.41 | 5.76 | 8.13 | 14.92 | 6.10 | | | | | | | |
| Idle-Machine in Motion | | | | | | | | | | | | | | |
| Idle-Otherwise | | | | | | | | 6.10 | 6.10 | - | 5.42 | 13.22 | 11.52 | 8.47 |
| Move to New ₁ /Position | | | | | | | | | | 42.71 | 16.95 | 14.58 | 9.49 | 28.82 |
| Personal Time | | | | | | | | | | | 1.70 | - | 2.72 | 2.37 |
| % Pro-ductive | 93.90 | 93.90 | 57.29 | 75.93 | 70.50 | 71.53 | 57.97 | | | | | | | |
| % Unpro-ductive | | | | | | | | 6.10 | 6.10 | 42.71 | 24.07 | 29.50 | 28.47 | 42.03 |

1/

Represents times when a worker goes to work with another person not immediately close to him.

* No identifiable cycle.

Jumbo machine was in motion, while five men remained idle; why a man, Man 3, was idle for 43% of the time; and why one man, Man 6, was involved in almost all the unloading operation across the width of the equipment. He would also like to know whether the steel lapping and tying crew which followed the steel placing incurred still further delays.

In the opinion of the analyst, the non-uniformity in production times was largely due to the failure to develop a defined working cycles in which each workman had specific tasks to perform. The number of men on the Jumbo Satellite might be increased from 7 to 8, thereby permitting the identification of four groups of two persons each. The contractor could then arrange to have four steel stockpiles, one for each group, with each group held responsible for its own steel unloading and positioning. The unloading time would probably be increased by the proposed arrangement unless the cradle was suitably modified. If the hooks around the steel were air operated, the workers would merely have to unhook the steel. There would then be a continuous cycle, with the mobile crane supplying each group in turn rather than at random.

There may also be some concern as to whether the steel tiers would be able to keep up with this improved method. Between 8 to 10 men were observed to be doing the lapping and tying. It was not possible to record the steel tying operation because of the limited view of vision.

An unanswered question is why the mobile crane was used to tow the Jumbo machine. This piece of equipment is supposed to be self propelled. Since the analyst is not familiar enough with its operation to provide an explanation, a call back to the contractor revealed that this measure was undertaken in emergency cases when it was necessary for the Jumbo machine to get to a new position as quickly as possible.

The Jumbo Satellite is potentially a highly productive unit. It is believed that, with better planning, it could lay longitudinal steel at a substantially faster rate than the mile per day which it has accomplished thus far. However, the contractor recognizes that even the present output of the machine was impossible only a few years back.

Job 2: Rebar Installer

Job Details

Location:

I-35 South, Lamoni, Iowa.

Job Specifications:

Same as Job 1 except steel at 4" depth and crown about 2".

Steel Specifications:

Longitudinal Reinforcement

| | |
|-----------------|---------------|
| Length of bars | 42' |
| Spacing of bars | 6" on centers |
| Lap | 18" |

| | |
|-----------------------------------|-----------|
| Lap Stagger | 4' |
| Connection | Wire tied |
| Placement Method: Rebar Installer | |
| Tie Bars | |
| Length | 36" |
| Size | 1/2" |
| Spacing | 36" |
| Placement Method: Same as Job 1 | |

Hauling and Placing of Steel:

Storage Yard Equipment: Hough front end loader used to pick up bars from stock pile.

Hauling Equipment: One semi owned by contractor and ten owned by agent to carry steel to storage yard. Two were used to carry steel to site.

Steel Placing Equipment: Two semi trucks and one mobile crane were used to place the steel on site.

Labor to Lay Steel:

| | <u>Number</u> |
|---------------|---------------|
| Hough loader | 1 |
| Laborers | 2 |
| Truck drivers | <u>2</u> |
| Sub Total | 5 |

Labor to Lay Steel:

| | |
|--|----|
| Truck driver helpers | 2 |
| Crane operator | 1 |
| Bar laying crew (Crews 1, 2, 3 & 4) | 12 |

| | | |
|-----------------|----------|-----------|
| Bar tieing crew | <u>6</u> | |
| Sub Total | | 21 |
| Tie bar crew | 1 | 1 |
| Foreman | <u>1</u> | <u>1</u> |
| Grand Total | | <u>28</u> |

Average Length of Steel Laid Per 10 hr. day: 6000'

Concrete Production: Central Plant

| | |
|---------------------------------|----------------------|
| Capacity of Plant | 450 cu. yds/hr. |
| Capacity of Hauling Units | 8 cu. yds. |
| No. of Hauling Units | 8 - 18 trucks |
| Average Quantity Placed Per Day | 2500 - 3000 cu. yds. |
| Average Length Paved Per Day | 4000 - 5000' |

Description of Paving Train:

Rex Belt Placer

Rex Slipform Paver

Operator Experience: 4 yrs.

Rex Rebar Installer attached to the front of slipform
paver

Rex Burlap Machine

Roy Carlson Spray Cure Machine

Description of Job Method

Steel was carried from yard by two semi trucks and stock piled by the road side by two laborers standing on the truck. From here laborers in groups of three picked up one bar at a time laid and lapped them; 6 men of tieing crew then tied the bars at laps.

At the beginning of the paving job, the bars were fed over the spreader as described in the operation of the rebar installer (Part II) and were depressed as described, see Figures 47 - 51. Immediately after the belt placer, stood a man who deposited the tie bars at premeasured distances.

The slab was finished by the slipform paver and hand floated by finishers.

The slab was then burlapped and spray cured with linseed oil and kerosine mixture.

Comments:

This slab was continuously checked for depth and the position of steel. It was very satisfactory. (See Figure 52).

The steel was depressed to the middle of the slab. Contractor has slipformed 16 ft. uniform width ramp and, in fact he slipforms all his ramps.

Analysis of Steel Placement Operation

This contractor used one mobile crane, two semi trucks, four steel laying crews containing three men per crew, and a steel tying crew containing six men, to lay 42 ft bars spaced 6 in. apart over an average distance of 6000 ft during each 10 hr day. Steel was brought to the site in semi-trucks, tied in bundles of 48 bars. Each bundle was hooked to the boom of a mobile crane by two men standing on the truck. The crane then carried the steel and placed it on

either side of the subgrade. The steel was unhooked by one man who also moved the truck whenever this became necessary. Groups 1 and 2 of the four steel laying groups operated on the first 12 ft width of the subgrade. Groups 3 and 4 worked about 400 ft behind the first two groups, and laid steel on the second half of the subgrade. The operation began with the men in Group 1 carrying a bar and positioning it at the center of the subgrade. The group would then go back to the stockpile, pick up another bar, position it 6 in. away from the first bar and lap it. A preset template was used to aid in positioning the bar. This operation would be continued until twelve rows of bars had been placed and lapped. The group then would move forward one bar length and start a new line continuous with the first. As the first group moved up, the second group, Group 2, would move in to place a second row of 12 bars to complete the 24 bars for the side. Similar operations were being performed by Groups 3 and 4 on the other side of the subgrade. The placing operation was continuous and it was easy to identify distinct cycles for both the mobile crane and the steel laying crews. After the steel laying crew came the 6-man steel tying crew who did the tying at laps.

The analysis focused upon the individual groups because the three men in each group did exactly the same thing at the same time. Studies were confined to Groups 1 and 2, since it appeared that the performances of these two groups would be representative of the four groups.

About 6-10 minutes of working time was lost by the workers and the crane while they were waiting for the steel truck to come to the site. This was the major laxity observed in the operation. Although it could be viewed as a scheduling problem, it gave the steel setters some time to rest. As can be seen from Tables 6 and 7, the mobile crane and the steel placers hardly had any idle time. To maintain the efficiency of workers who are performing medium to heavy manual labor, it is usually considered necessary to have rest periods of 28-30% of the work time (67). If this is true, one might conclude that the truck delays served to provide the workers with some badly needed rest periods.

The tabulated productive times show that the first group of steel setters was productive for 63% of the time whereas the second group was productive for only 44%. However, a further look at the work elements involved with each group reveals that the second group spent 8.4% of its time waiting for Group 1 to finish up! If one also observes the period taken to complete the cycles, it can be seen that Group 2 completed its operation in significantly less time than Group 1 (12.95 secs to 17.18). The explanation is a simple one. Group 1 carried its steel a greater distance than did Group 2 since it always started its steel positioning at a distance of 12 ft from the shoulder and proceeded to a point about 6 ft from the shoulder. The second group then positioned the steel to the edge of the roadway. A better

Table 6. Times Spent on Various Activities by the
Mobile Crane

| | |
|--------------------------------|-------------------------------|
| Job No.: <u>2</u> | Location: <u>I-35 S, Iowa</u> |
| Contractor: <u>Roy Carlson</u> | By: <u>oto</u> |
| Film No.: <u>2</u> | Date: <u>7-7-70</u> |

| | | |
|----------------------------|----------------|------------------|
| Activity | Productive (%) | Unproductive (%) |
| Return to Stockpile | 17.65 | |
| Load Steel | 27.94 | |
| Carry Steel | 10.78 | |
| Position Steel | 7.11 | |
| Delay - No trucks | | 28.19 |
| Delay - by Popemen | | 8.33 |
| | <hr/> | |
| % Productive | 63.48 | |
| % Unproductive | | 36.52 |
| | <hr/> | |
| Average Cycle Time (mins.) | | |
| With Delays | 2.37 | |
| Without Delays | 1.44 | |

Table 7. Times Spent on Various Activities by Two Groups of Reinforcing Steel Setters, Job 2

| Activity | Productive (%) | | Unproductive (%) | |
|-----------------------------------|----------------|---------|------------------|---------|
| | Group 1 | Group 2 | Group 1 | Group 2 |
| Return to Stockpile | 10.97 | 11.24 | | |
| Sort Steel | 22.45 | 10.30 | | |
| Carry Steel | 14.97 | 12.18 | | |
| Position Steel | 14.47 | 10.77 | | |
| Move to New Position | | | 10.97 | 9.37 |
| Wait for Another Trade | | | | 8.43 |
| Delay - No Trucks | | | 26.17 | 28.35 |
| Idle | | | | 9.37 |
| % Productive | 62.86 | 44.48 | | |
| % Unproductive | | | 37.14 | 55.52 |
| Average Cycle Time (secs.) | | | | |
| | Group 1 | | Group 2 | |
| Excluding Unproductive Activities | 17.18 | | 12.95 | |
| Including Unproductive Activities | 30.57 | | 29.13 | |

method might have been to place the steel bundles in three positions across the subgrade - a bundle of 24 bars in the center of the roadway and 12 bars on the shoulder. Each group would then walk an equal distance.

In the opinion of the author, this job was a well planned job. Its major shortcoming was the one just described, wherein the performance of one group was reduced because it was dependent on the performance of another group. The effectiveness of planning the job was reflected in the 6000 ft of steel that the contractor was able to lay per day.

Job 3: Rebar Installer

Job Details

Location:

I-29 South, Grand Forks, North Dakota.

Job Specifications:

CPC pavement 8" thick, 24' wide, 5/8" deformed bars, placed 4" below the surface with the option of omitting transverse bars; 1-1/2" parabolic crown.

Steel Specifications:

Longitudinal Reinforcement

| | |
|-----------------|-------------------|
| Length of bars | 60' |
| Spacing of bars | 6-1/2" on centers |
| Lap | 18" |
| Lap stagger | 4' |
| Connection | Wire tied |

Placement Method: Contractor built rebar installer
Tie Bars

| | |
|---------|------|
| Length | 30" |
| Size | 5/8" |
| Spacing | 30" |

Placement Method: By hand from rotating notched
drum

Hauling and Placing of Steel:

Storage Yard Equipment: Two mobile cranes. Steel is
brought in by rail.

Hauling Equipment: Two semi trucks

Steel Placing Equipment: One mobile crane

Labor to Move Steel to Site:

| | |
|-----------------|---------------|
| | <u>Number</u> |
| Crane operators | 2 |
| Truck drivers | 2 |
| Laborers | <u>2</u> |
| Sub Total | 6 |

Labor to Lay Steel:

| | | |
|------------------------------------|----------|------------------|
| Placing crew (Groups 1, 2, 3, 4) | 16 | |
| Tieing crew | 4 | |
| Crane operator | 1 | |
| Truck driver helpers (man 1, 2, 3) | <u>3</u> | |
| Sub Total | | 24 |
| Tie bar crew | 1 | 1 |
| Foreman | <u>1</u> | <u>1</u> |
| Grand Total | | <u><u>30</u></u> |

Average Length of Steel Laid per 10 hr. Day: 4000'

Concrete Production: Central Plant

| | |
|---------------------------------|------------------|
| Capacity of Plant | 320 cu. yds./hr. |
| Capacity of Hauling Unit | 8-9 cu. yds. |
| No. of Hauling Units | 8 trucks |
| Average Quantity Placed per Day | 3500 cu. yds. |
| Average Length Paved per Day | 3600-4000' |

Description of Paving Train:

Rex Belt Placer
 CMI Tube Finisher Float with Burlap
 CMI Slipform Paver
 Schultz and Lindsay Rebar Installer
 CMI Tube Finisher
 Barton Spray Cure Machine

Description of Job Method:

Two semi trucks carried the bundles of steel from the yard and deposited them at the center of the roadway. Four groups of laborers, each group containing four people, then carried the bars individually and positioned and lapped them. Four more men did the tying.

The dumping of the concrete and the positioning of the bars were similar to the process described for the rebar installer in Part II.

The pavement was floated and burlapped with a CMI combination tube float burlap machine. It was cured with a mixture of linseed oil and water.

Comments:

This contractor had a 2 miles a day record. On the day in question, he had one Maxon and one Yeager spreader and was able to dump 3 trucks at a time. The contractor felt the use of continuous reinforcement slowed down his operation since he could only use a Rex belt placer and could dump only one truck at one time.

This contractor had built his own rebar installer, which was patterned after Rex's. The machine was not yet perfected, and had problems in meeting the specification tolerances, and it seemed to oscillate a little faster than the two observed on Jobs Nos. 1 and 2.

A mechanism at the back of the slipform paver automatically installed a polyethylene fiber in the pavements. This eliminated the need for sawing longitudinal joint and reduced costs. The fiber was 2-1/4" deep, or approximately one-fourth of the slab thickness. The contractor claimed that this installation method prevented the development of cracks. North Dakota formerly required a white pigmented curing compound, but in 1969 changed to a mixture of linseed oil and water in the belief that this would better protect the slab from salt during the winter. At the time of this study, the contractor was still experimenting to find the mixture proportions that would give the best results. Trials had been made with oil-water combinations of 40/60, 60/40, and 50/50.

Analysis of Steel Placement Operation

This contractor laid the steel by using a mobile crane, two semi trucks and four crews consisting of four men each. On the day these observations were made, one crew was absent.

Two men, using a 100 ft tape, marked position along the center of the subgrade where steel bundles were to be deposited. One man on the truck, who was also responsible for moving the truck, tied the bundles together and hooked them one at a time to a steel cradle attached to the cables of a mobile crane. The two men on the ground then positioned the steel bundles at the marked locations along the subgrade. After this positioning, one of the men on the subgrade climbed on the truck to help with the tying while the third man stayed on the ground. After the tying the man who had boarded the truck would get off, and would help the one on the ground position the steel by holding the other end of the bundle (the man on the ground holds the first end), and guiding the bundle to its proper position on the subgrade.

Some distance behind the steel depositors was the steel setting crew. If the full steel setting crew of 16 had been present, there would have been 8 men on each side. However, on the day in question, there were two four-man groups on one side and one four-man group on the other side. The first group placed the first set of 11 bars closest to the edge of the prepared subgrade, carrying one bar at a time and positioning it 6-1/2 in. from the previous bar by the use of a wooden template. This group would then

begin to place a second set of 11 bars as a continuation of the first set. Concurrently, the second group would move in and position the set of 11 bars closest to the center of the subgrade. A similar working sequence would normally be underway on the other side of the subgrade if the full crew was present. However, on the day of the observations, only one four-man crew was available to place the 22 bars on that side. After the steel placing crew came four men who did the tying.

In analyzing this job, attention was focused on the mobile crane, the reinforcing steel setters, and the three men who carried and positioned the steel bundles on the subgrade. Table 8 shows the percentages of time spent by the mobile crane on each of the work elements. The crane is shown to be 100% productive, but the analysis is not conclusive. The photographic records did not include a sufficient number of crane working cycles to permit a complete analysis.

The men who positioned the steel bundles along the subgrade were individually analyzed. The man who was always on the truck was designated as Man 1, the one who was continuously climbing and getting off the truck was Man 2, and the one who was always on the ground was Man 3. Table 9 shows the percentages of time spent by the each of the three men on various activities. Man 1 spent 31% of the working time in moving the truck. Man 2 spent almost 18% of his

Table 8. Times Spent on Various Activities by the
Mobile Crane*

| | |
|--|------------------------------------|
| Job No.: <u>3</u> | Location: <u>I-29 S. N. Dakota</u> |
| Contractor: <u>Schultz & Lindsay</u> | By: <u>oto</u> |
| Film No.: <u>3</u> | Date: <u>7-13-70</u> |

| Activity | Productive (%) | Unproductive (%) |
|---------------------|----------------|------------------|
| Return to Stockpile | 20.99 | |
| Load Steel | 25.93 | |
| Carry Steel | 35.80 | |
| Position Steel | 17.28 | |
| | <hr/> | |
| % Productive | 100.00 | |
| % Unproductive | | 0.00 |
| | <hr/> | |

* Study inconclusive. Only three cycles clearly identifiable.

Table 9. Times Spent on Various Activities by
Steel Placers, Job 3*

| Activity | Productive (%) | | | Unproductive (%) | | |
|----------------------|----------------|-------|-------|------------------|-------|-------|
| | Man No. | | | Man No. | | |
| | 1 | 2 | 3 | 1 | 2 | 3 |
| Hook Wires | 34.57 | | | | | |
| Wait for Crane | | | | 7.41 | | |
| Load Steel | 27.16 | 22.56 | | | | |
| Move Truck | | | | 30.86 | | |
| Return to Truck | | | | | 10.37 | |
| Climb Truck | | | | | 2.44 | |
| Get Off Truck | | | | | 4.88 | |
| Move to New Position | | | | | 21.34 | 22.23 |
| Support Steel | | | | | | |
| - Loading | | | | | | 28.37 |
| - Travelling | | 21.34 | 32.12 | | | |
| Position Steel | | 17.07 | 17.28 | | | |
| % Productive | 61.73 | 60.97 | 49.40 | | | |
| % Unproductive | | | | 38.27 | 39.03 | 50.60 |

* No identifiable cycle.

working time in getting on and off and returning to the truck. A possible alternative would be to have two men stay on the truck and another two men remain on the subgrade to position the steel. Man 3 spent 60% of his working time supporting steel on the truck and across the subgrade until it was positioned at the center of the subgrade. An alternative might be to build a device strong enough to carry the steel independently of the workers.

Although the analysis showed that the men were fairly productive, a more critical look at the work elements leads to the conclusion that Man 2 and Man 3 were only marginally effective. The construction of a stronger cradle and the addition of one more man on the truck would facilitate faster loading. With two men on the ground all the time, the unloading would also be faster.

In theory, the groups of reinforcing steel setters were not supposed to get in each other's way. As was noted in the analysis of Job 2, the group that placed steel on the section of the subgrade closest to the stockpile had an inherently shorter cycle time. See Table 7. Table 10 shows that this same factor affected the work of Groups 1 and 2 on Job 3. This table also shows that Groups 2 and 3 of Job 3 spent disproportionately large percentages of their time on unproductive items. As was suggested for Job 2, placing the steel at three positions on the subgrade would eliminate the unbalanced walking distances for the groups. Including one

Table 10. Times Spent on Various Activities by Three Groups of Reinforcing Steel Setters, Job 3

| Activity | Productive (%) | | | Unproductive (%) | | |
|-----------------------------|----------------|---------|---------|------------------|-------|-------|
| | 1 | 2 | 3 | 1 | 2 | 3 |
| Set Template | 3.45 | 3.52 | 1.89 | | | |
| Sort Steel | 25.00 | 16.90 | 6.44 | | | |
| Carry and Position Steel | 25.86 | 15.14 | 12.12 | | | |
| Return to Stockpile | 18.96 | 10.21 | 9.47 | | | |
| Move to New Position | | | | 6.90 | 9.86 | 18.94 |
| Personal Time | | | | | 19.72 | 28.79 |
| Wait for Another Group | | | | | 16.20 | |
| Idle | | | | 19.83 | 8.45 | 22.35 |
| % Productive | 73.27 | 45.77 | 29.92 | | | |
| % Unproductive | | | | 26.73 | 54.23 | 70.08 |
| Average Cycle Time (secs.) | | | | | | |
| | Group 1 | Group 2 | Group 3 | | | |
| With Delays | 29.00 | 41.10 | 66 | | | |
| Without Delays | 20.25 | 16.50 | 17 | | | |

more man on the steel bundling crew, as has already been suggested, would facilitate the placement of the steel in three different positions since the loading and the unloading could then be done faster. The disproportionate lengths of time spent by both Group 2 and 3 were reflected in the daily production rate. The three groups laid only 2500 ft and the average for the complete crew was reported to be 4000 ft per 10 hour day. The contractor might be tempted to blame this on an inadequate crew, but an analysis along the lines just presented would suggest that there are additional causes for his unsatisfactory production.

Job 4: Chair Supports

Job Details

Location:

I-94 West, Rothsay-Moorehead, Minnesota

Job Specifications:

8" CRC pavement, placed on chairs, 24' wide, with 2.88 in. parabolic crown, reinforced with deformed bars, 4-5" above subgrade.

Steel Specifications:

Longitudinal Reinforcement

| | |
|-----------------|-----------------|
| Size of bars | 5/8" |
| Spacing of bars | 5.4" on centers |
| Length of bars | 60' |
| Lap | 18" |

| | |
|--|---------------------|
| Lap stagger | 12'-16' across slab |
| Connection | Wire tied at laps |
| Placement Method: Clipped to transverse bars | |
| Transverse Reinforcement | |
| Size of bars | 5/8" |
| Spacing of bars | 4' on centers |
| Length of bars | 13.75' |
| Lap | 2' |
| Lap stagger | None |
| Placement Method: Welded to chairs | |

Hauling and Placing of Steel:

Storage Yard Equipment: 2 mobile cranes. Steel is stockpiled at railroad station and brought directly to site.

Hauling Equipment: 2 semi-trucks.

Steel Placing Equipment: One mobile crane, one semi-truck, one contractor-built steel placer (see Figure 57).

Labor to Move Steel to Site:

| | <u>Number</u> | |
|----------------|---------------|----|
| Crane operator | 2 | |
| Laborer | 6 | |
| Truck driver | <u>2</u> | |
| Sub Total | | 10 |

Labor to Lay Steel:

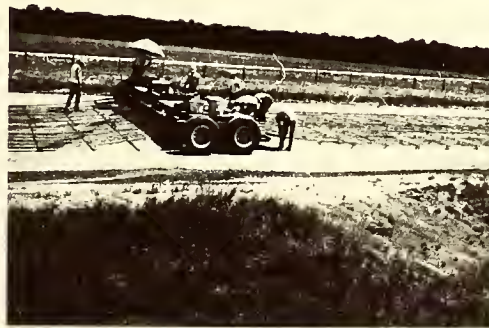
| | |
|-------------------|----|
| Longitudinal crew | 12 |
| Transverse crew | 6 |
| Tieing crew | 5 |



1.



2.



3. & 4.

Figure 57

Enumerated Procedure for Laying Steel on Chairs

1. Transverse bars to which chairs have been previously welded are laid on the subgrade.
2. Workmen, in groups of four, pick 60 ft. long bars from the subgrade and lay them on the chairs.
3. These men are followed by a contractor-built machine (with spacing notches) which correctly spaces the bars.
4. Behind the machine are men who clipped the chairs to the longitudinal bars.

| | | |
|------------------------|----------|-----------|
| Clipping crew | 2 | |
| Crane operator | 1 | |
| Truck driver | 1 | |
| Chair machine operator | 1 | |
| Chair machine helper | <u>1</u> | |
| Sub Total | | 29 |
| Foreman | <u>1</u> | <u>1</u> |
| Grand Total | | <u>40</u> |

Average Length of Steel Placed per 10 hr. Day: 4500'

Concrete Production: Central Plant

| | |
|---------------------------------|------------------|
| Capacity of Plant | 550 cu. yds./hr. |
| Capacity of Hauling Unit | 7-1/2 cu. yds. |
| Number of Hauling Units | 12-17 trucks |
| Average Quantity Placed per Day | 3350 cu. yds. |
| Average Length Paved per Day | 4700' |

Description of Paving Train:

CMI Belt Spreader Placer
 Rex Slipform Paver - Operator experience: 4 yrs.
 Rex Belter Burlap Machine

Description of Job Method:

A mobile crane and a semi placed bundles of 60 ft longitudinal bars beside the subgrade. Another semi carried the transverse bars and the 3-man transverse bar crew. The transverse bars had been welded in the shop and had clips for the longitudinal bars. After marking the position of the transverse bars by the use

of a template, the transverse crew positioned the bars on their sides. The longitudinal bar crew then positioned the longitudinal bars on the transverse bars. The hooking or clipping crew which followed on a self-propelled machine clipped the chairs to the longitudinal bars. This crew was followed by a crew of two men who finally clipped all the bars.

The paving operation, using a CMI belt placer and a Rex slipform then followed.

The pavemnet was then hand-finished, burlapped and cured with polyethylene sheets.

Comments:

Despite the high level of mechanization, this contractor still needed 40 men to place steel on chairs. The job demonstrated that the installation of chair supports requires a lot of labor.

Analysis of Steel Placement Operation

This contractor employed 40 men for steel placing, the largest group of all the contractors observed. Three men and a truck driver started the operation. The truck carried transverse steel bars on which had been welded chairs and clips for the longitudinal steel. The first man stood on the subgrade, using a set of templates. The second man, standing on the truck, then handed two bars at a time to the third man who stood on the subgrade. The third man would then lay the bars on the previously marked positions on the

subgrade. This operation was not analyzed because it was not possible to observe all three men at the same time. The camera's view was obstructed by the semi truck that the men were using, and there was no frontage or access road close by to provide a convenient observation station. See Figure 57.

The second part of the operation involved three groups, each of which consisted of four men, and a separate stockpile of steel for each group. The placing plan required each group to go to its stockpile at the side of the subgrade, where the bars had been previously deposited, and then carry a number of bars all the way across the subgrade before positioning and spreading them. While the first group was walking across the subgrade, the second group was sorting steel at its starting point and the third group was waiting. At about the time the first group was ready to position and spread its load of steel, the second group would leave its stockpile and the third group would begin to sort its steel load. By the time the first group had positioned its steel and was on its way back to its stockpile, the second group was positioning and distributing its load. By the time that the first group was back at its stockpile, the second group had positioned its load and was returning to the stockpile. The third group would then position and distribute its steel. By the time the third group had positioned its steel, the second was back at the stockpile and the first was moving away from the stockpile. The cycle would repeat until all

the bars had been placed across the subgrade, which usually required about three cycles. The crews would then move to a new position. After the placing operation came the tying crew of six men. This crew was followed by a self-propelled machine which used a roller to pick up the longitudinal bars from the subgrade. This, in turn, was followed by six men who partially hooked the transverse bars to the longitudinal bars. Each of these men carried a 4 ft steel rod which he used to check the spacing of the transverse bars before these bars were clipped to the transverse bars. See Figure 57. These men were followed by two other men who completed the clipping operation across the subgrade.

The steel placing crews were analyzed as three groups. Each group was observed individually to calculate its cycle time. Table 11 shows the percentages of time spent on various activities. The second group had the greatest percentage of productive time of the three groups, but this does not mean that it worked most efficiently. A look at the average cycle times indicates that Group 2 took for longer per cycle than either of the other two groups and therefore got in the way of the others.

The working plan required the crew members to walk all the way across the subgrade each time a new cycle was started. This distance, of course, decreased progressively as the group approached the stockpile. If the steel had been deposited on both sides of the subgrade, and if the

Table 11. Times Spent on Various Activities by Three Groups of Reinforcing Steel Setters

| Job No.: <u>4</u> | Location: <u>I-94 W. Minn.</u> | | | | | |
|-----------------------------------|--------------------------------|---------|---------|------------------|-------|-------|
| Contractor: <u>Woodrich</u> | By: <u>oto</u> | | | | | |
| Film No.: <u>3</u> | Date: <u>7-22-70</u> | | | | | |
| Activity | Productive (%) | | | Unproductive (%) | | |
| | 1 | 2 | 3 | 1 | 2 | 3 |
| Sort Steel | 42.62 | 30.56 | 26.23 | | | |
| Carry Steel | 12.30 | 13.89 | 11.48 | | | |
| Position and Distribute Steel | 19.67 | 31.94 | 34.47 | | | |
| Return to Stockpile | 9.02 | 11.11 | 11.47 | | | |
| Move to New Position | | | | 16.39 | 12.50 | 16.39 |
| % Productive | 83.61 | 87.50 | 83.61 | | | |
| % Unproductive | | | | 16.39 | 12.50 | 16.39 |
| Average Cycle Time (secs.) | | | | | | |
| | Group 1 | Group 2 | Group 3 | | | |
| Excluding Unproductive Activities | 52.50 | 75.00 | 55.50 | | | |
| Including Unproductive Activities | 67.50 | 88.50 | 70.50 | | | |

crew of twelve had been divided into two parts so that six started from each side and moved towards the center, the average walking distance would have been substantially reduced. Admittedly, a crew of three could not carry as large a load as a crew of four, but the savings in time would have permitted additional trips to the stockpile. The men responsible for hooking the chairs could not be studied together because they were all doing the same thing at almost the same time. Therefore the activities of the two men closest to the camera were analyzed as representative of the group. As can be seen from Table 12, these two men had identical times for checking the spacing and for hooking chairs. The lack of any specific cycle for the chair hooking operation, contributed to the differences in the idle times and the times for moving to new positions.

The entire operation served to demonstrate that a large amount of labor is expended when the rebar reinforcement for CRC pavements is supported on chairs. The use of transverse bars also complicated the operation and added to its cost. Eleven men were directly associated with laying and positioning the transverse chairs: three men spotted the chairs on the subgrade, six hooked the chairs, and two finished the clipping of the longitudinal bars to the transverse bars. Deletion of the transverse bars would have eliminated the need for these eleven men. If two additional men were used to unload steel bundles on the two sides of the subgrade, the net result would still be the elimination of nine men.

Table 12. Times Spent by Two of the Men Who Hooked Chairs to the Longitudinal Bars, Job 4*

| Activity | Productive (%) | | Unproductive (%) | |
|----------------------------|----------------|-------|------------------|-------|
| | Man 1 | Man 2 | Man 1 | Man 2 |
| Check Space and Hook Chair | 61.36 | 61.36 | | |
| Move to New Position | | | 18.94 | 25.00 |
| Idle | | | 19.70 | 13.64 |
| % Productive | 61.36 | 61.36 | | |
| % Unproductive | | | 38.64 | 38.64 |

* No identifiable cycle.

Job 5: Mesh Depressor - Rex

Job Details

Location:

I-94 West, Rothsay - Moorhead, Minnesota

Job Specifications:

9" jointed pavement, 24' wide, reinforced with D 4.9
x D 4 wire fabric and dowel baskets, placed about
3-1/2" below the surface with 1-1/2" crown.

Steel Specifications:

| | |
|-------------------------------|----------------|
| Length of Sheet | 18' |
| Width of Sheet | 11' |
| Spacing of Longitudinal Wires | 6" on centers |
| Spacing of Transverse Wires | 12" on centers |
| Length of End Laps | None |

About 9' gap is left between sheets. Most of the
space is occupied diagonally by the dowel assembly.

| | |
|--|------|
| Stagger | 2' |
| Length of Overlap of Sides of Longitudinal Wire | None |
| Edges are separated about | 6" |

Placement Method: Full depth by Mesh Depressor

Tie Bars

| | |
|---------|----------------|
| Length | 30" |
| Size | 5/8" |
| Spacing | 30" on centers |

Placement method: Rotating notched drum

Hauling and Placing of Steel:

Storage Yard Equipment: One mobile crane

Hauling Equipment: Two semi trucks

Steel Placing Equipment: One mobile crane and one mesh cart

Labor to Move Steel to Site:

| | <u>Number</u> | |
|-----------------|---------------|---|
| Crane Operators | 1 | |
| Truck drivers | <u>2</u> | |
| Sub Total | | 3 |

Labor to Lay Steel:

| | | |
|----------------|----------|------------------|
| Crane Operator | 1 | |
| Oiler | 1 | |
| Mesh crew | 6 | |
| Laborers | 5 | |
| Tie bars | 1 | |
| Foreman | <u>1</u> | |
| Sub Total | | <u>15</u> |
| Grand Total | | <u><u>18</u></u> |

Average Length of Steel Placed Per 10 hr. Day: 2400'

Concrete Production: Central Plant

| | |
|---------------------------------|-----------------|
| Capacity of Plant | 500 cu.yds./hr. |
| Capacity of Hauling Unit | 9 cu. yds. |
| Number of Hauling Units | Not Available |
| Average Quantity Placed per Day | 2100 cu. yds. |
| Average Length Paver per Day | 3500' |

Description of Paving Train:

CMI Belt Spreader-Placer

Rex Mesh Depressor

Central State Mesh Cart

Central State Joint Machine

Rex Slipform Paver

Operator experience: 12 yrs.

Description of Job Method:

This was an experimental project on which both the 5" cement treated base and the mesh depressor were tested. Dowel baskets were laid on the prepared cement treated subbase. These were fixed on one side and loose on the other to allow movement during changes in temperature. A CMI belt placer supplied by rear dump trucks placed the concrete full depth.

Behind the placer was a mesh cart. Five men lifted the mesh from the cart and placed it on the concrete, while another man installed the tie bars. Following the cart was a Rex Mesh Depressor, attached to the front of the Rex Slipform Paver. This depressed the steel to the prescribed depth. The slipform paver then finished the slab. Hand floats were used as in the previous operations.

Joint sawing machine then followed and installed joints every 100' and the surface was refinished.

The burlap machine and the polyethylene sheet machine followed the saw operation.

Comments:

The number of men used to place mesh was close to half of that used to place the steel for chair supported CRC pavement. Of course, this pavement was not continuously reinforced.

This contractor has used a slipform paver continuously since 1958. He still has a Quad City Company paver (first slipform paver; builder sold its rights to Rex Chainbelt) which he plans to modify for use in ramp paving. The state now uses a uniform ramp width of 16 ft.

The contractor had previously had experience with mesh depressors. The discrepancy between the length of steel laid and the length paved resulted from the fact that a gap of 9 ft was left after each mat.

Analysis of Steel Placement Operation

This contractor used two semi trucks to bring the reinforcing steel to the site. Two men then hooked bundles of the mesh together and attached the ends of the cable to the hook of a mobile crane. The crane stockpiled the loads of mesh on a mesh cart which was attached to the rear of a belt spreader. See Figure 58. Two workers then unhooked the mesh.

In placing the mesh, two of the five or six men working in the full depth concrete pulled one end of the sheet at a preset position and stood on the mesh so that it drew itself off as the belt-placer moved forward. Three or four more

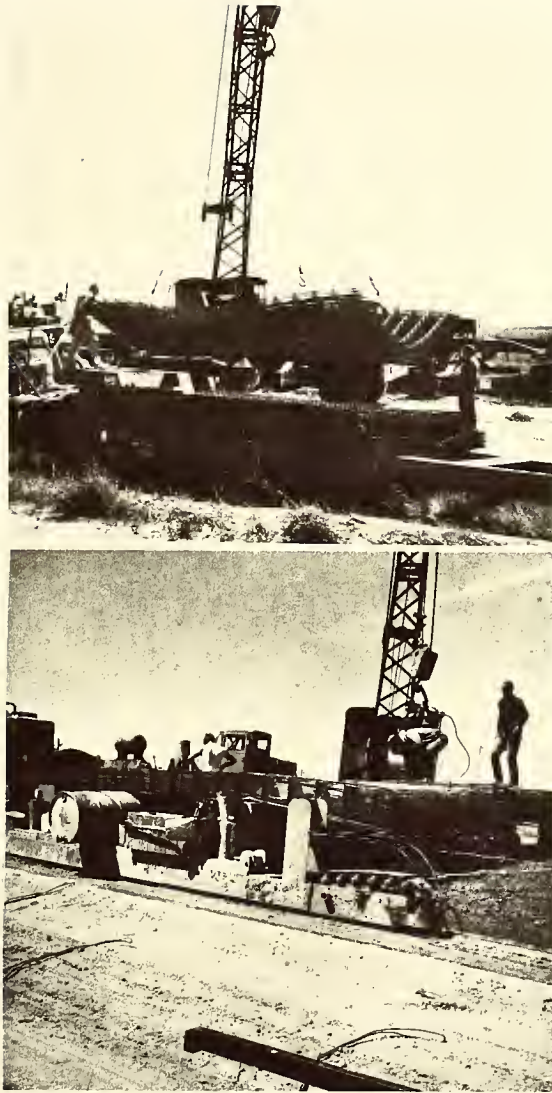


Figure 58

Sheets of Mesh are Stockpiled on a Mesh Cart

workers stepped onto the mesh as it was being drawn off. Since the pavement was a jointed type, the mesh was not tied or lapped. It was placed at specified intervals on the full depth slab and was depressed from the surface by a Rex mesh depressor.

There was no identifiable pattern in the way that the mesh was placed. Several persons moved back and forth, and it was impossible to correlate these people with specific tasks. In fact, their movements became so confused that the analyst was unable to derive any useful conclusions from the data. The erratic labor movements appeared to be due to improper distribution of concrete by the belt placer. This made it necessary to take the men away from the mesh laying operations and use them to correct the paving imperfections. When the men returned to mesh laying, they did not necessarily resume the same work which they had performed previously. The continuous shift of labor was reflected in the average daily progress of the contractor. This amounted to 3500 ft, one of the lowest of any of the slipform operations which were observed during this study.

The uneven distribution of the concrete across slab width could have been due to a lack of experience on the part of the belt-placer operator. Most of the concrete seemed to be distributed near the center of the roadway, leaving large spaces on the sides. To fill these gaps, the whole paving operation had to be stopped and loaders brought in to

dump concrete. The laborers would then respread the concrete before the paving operation could continue. As mentioned earlier in this report, skilful operation of the modern electronically controlled motor graders, spreaders and slipform pavers is essential to high productivity. Delays are very costly, as was demonstrated by the experiences of this contractor.

Job 6: Mesh Depressor - Heltzel

Job Details

Location:

I-69, near Indianapolis, Indiana

Job Specification:

9" thick CRC pavement 24' wide reinforced with mesh placed at 4" \pm 1/2 below the surface, with option of using a mesh depressor on forms and 2-1/2" straight crown.

Steel Specifications:

| | |
|-------------------------------|----------------|
| Length of Sheet | 24' |
| Width of Sheet | 6' |
| Spacing of Longitudinal Wires | 4" on centers |
| Diameter | 1/2" |
| Spacing of Transverse Wires | 12" on centers |
| Diameter | 1/4" |
| Weight of Sheet | 400 lb. |
| Length of End Laps | 16" |
| Stagger | 4' |

Placement Method: Full depth by form riding mesh depressor.

Hauling and Placing of Steel:

Storage Yard Equipment: None

Hauling Equipment: Semi-trucks

Steel Placing Equipment: Two mobile cranes, Heltzel Mesh Depressor, mesh hook.

Labor to Move Steel to Site:

| | | |
|---------------|---------------------------|---|
| Truck drivers | <u>Number</u> <u>2</u> | |
| Sub Total | | 2 |

Labor to Lay Steel:

| | | |
|-----------------|----------|-----------|
| Laborers | 7 | |
| Tieing crew | 2 | |
| Crane operators | 2 | |
| Oiler | 1 | |
| Foreman | <u>1</u> | |
| Sub Total | | <u>13</u> |
| Grand Total | | <u>15</u> |

Average Length of Steel Laid per 10 hr. Day: 3200'

Concrete Production: Central Plant

| | |
|----------------------------------|------------------|
| Capacity of Plant | 720 cu. yds./hr. |
| Capacity of Hauling Unit | 8 cu. yds. |
| Average Quantity Placed per Day: | 2200 cu. yds. |
| Average Length Paved Per Day: | 3000' |

Description of Paving Train:

Maxon Dumpcrete Spreader

Heltzel Mesh Depressor

Rex Finisher Float

Combination Spray Cure and Broom Machine

Description of Job Method:

Road forms were laid on the prepared subgrade and the chain of equipment was lined up on the forms. The 8 yd. Maxon side dump trucks carried the concrete and dumped it in the Maxon spreader, which placed it at a depth of 9 in. A semi-truck carried the steel mesh to the concrete. Three men on the truck hooked the mesh to a mesh hook attached by a cable to the crane. The mobile crane then carried it and placed it on the concrete. Five workers on the concrete lapped and staggered the mesh while another two did the tieing. The mesh depressor, riding on forms, then vibrated the steel to the specified depth. Rex finisher and float machines followed to finish the slab. A combination brooming and spray cure machine completed the construction.

Comments:

Indiana permits the use of vibration machines to depress steel only when the machines ride on forms. This type of machine was first used in the State in 1962. Its performance appears to have been satisfactory since its use is still permitted. The State also has experimented with a CMI mesh depressor which uses low amplitude vibration to depress the steel. This unit was tested on a project near Boswell, Indiana, during the summer of 1970. For further details, see Job 8 in this report.

Analysis of Steel Placement Operation

A semi truck brought the mesh load to the site and moved parallel to the road forms. A mobile crane carrying a contractor-built mesh grid then moved to position behind the mesh truck. The grid was lowered to the surface of the mesh load and two workers standing on the truck hooked one mesh sheet to the grid. The grid was then carried to the pit by the crane where four workers, standing in the previously laid full depth concrete between forms, positioned the steel and unhooked the mesh. Two steel tiers then tied the steel at laps. This operation was continued until the steel had been placed across the width of the slab. The steel crew then moved to a new position while a Heltzel mesh depressor vibrated the steel to position. See Figure 59.

Space limitations were such that the camera could not be positioned to obtain a good view of the entire operation. Consequently very limited data were obtained. The movement of the mobile crane could not be observed very well; one of the two men standing on the semi-truck was completely obscured from view by the steel pile; and his counterpart was partially blocked from view by the booms of the crane. It was also impossible to follow the pitmen who positioned the steel on the plastic concrete. Only one of the four men was visible most of the time and his activities were therefore assumed to be representative of those of the other steel setters. The two tiers were visible for a major part of the time.



Figure 59

Sheets of Mesh are Positioned on Full Depth Plastic Concrete

The analysis of the mobile crane was inconclusive. The figures shown in Table 13 are based on only three cycles of operation. Pitmen were idle for much of the time, since their only activities were to lap and unload steel. An analysis of one man's activities is supplied in Table 14. The steel tiers were also marginally productive. The first one was only 41% productive and the second only 40%. See Table 15.

It seemed that one trade was always waiting for another to complete its work. The steel tiers had to wait for the steel placers to finish, or vice versa. The steel placers had to wait for the men on the steel truck to finish, or vice versa. There appeared to be a lack of good planning to properly coordinate the activities of the workers. The six men working on the concrete, the four placers and the two tiers, were always getting into each other's ways. The lack of organization was reflected in the contractors rate of 3200 ft of steel per day. It is believed that the efficiency of the operation would be improved if two of the laborers used to place the steel were eliminated. The two steel tiers could then help with the placing and tying of the steel.

Job 7: Tube Assembly Augmented with Giant Spiral Blades

Job Details

Location:

I-70 West, Casey, Illinois.

Job Specifications:

CRC Pavement, 8" thick. 24' wide, 5/8" deformed bars,

Table 14. Times Spent on Various Activities by One
Steel Setter, Job 6*

| Activity | Productive (%) | Unproductive (%) |
|-----------------------|----------------|------------------|
| Load and Unload Steel | 22.17 | |
| Idle | | 77.83 |
| % Productive | 22.17 | |
| % Unproductive | | 77.83 |

* No identifiable cycles.

Table 15. Times Spent on Various Activities by the
Two Steel Tiers, Job 6*

| Activity | Productive (%) | | Unproductive (%) | |
|------------------------|----------------|-------|------------------|-------|
| | Man 1 | Man 2 | Man 1 | Man 2 |
| Tie Steel | 46.52 | 40.87 | | |
| Idle | | | 38.26 | 40.43 |
| Wait for Another Trade | | | 10.87 | 10.87 |
| Move to New Position | | | 4.35 | 7.83 |
| % Productive | 46.52 | 40.87 | | |
| % Unproductive | | | 53.48 | 59.13 |

* No identifiable cycles.

3" below the surface with the option of omitting transverse steel, 2-1/4" straight crown.

Steel Specifications:

Longitudinal Reinforcement

| | |
|-----------------|-------------------|
| Length of bars | 40' |
| Spacing of bars | 6-1/2" on centers |
| Lap | 16" |
| Lap stagger | 3' |
| Connection | Wire Tied |

Placement Method: Tube assembly augmented by a giant wheel with spirally twisted plates in front of paver (Figure 46).

Tie Bars

| | |
|---------|------|
| Length | 30" |
| Size | 5/8" |
| Spacing | 30" |

Placement Method: Rotating notched drum behind spreader

Hauling and Placing of Steel:

Storage Yard Equipment: None, steel was carried directly to site from supplier.

Hauling Equipment: Six semi-trucks each carrying 880 bars at a time.

Steel Placing Equipment: One mobile crane

Labor to Move Steel to Site:

| | |
|-----------|---------------|
| Laborers | <u>Number</u> |
| | 3 |
| Sub Total | 3 |

Labor to Lay Steel:

| | | |
|-------------------|----------|-----------|
| Steel laying crew | 12 | |
| Steel tying crew | 5 | |
| Crane operator | 1 | |
| Oiler | <u>1</u> | |
| Sub Total | | 19 |
| Tie Bar crew | 1 | 1 |
| Foreman | 1 | <u>1</u> |
| Grand Total | | <u>24</u> |

Note: Contractor did not pay for the truck drivers
who bring steel to site.

Average Length of Steel Laid per Day: 5200'

Concrete Production: Central Plant

| | |
|----------------------------------|------------------|
| Capacity of Plant | 400 cu. yds./hr. |
| Capacity of Hauling Unit | 9 cu. yds. |
| Number of hauling units: | Depends on need |
| Average Quantity Placed per Day: | 3200 cu. yds. |
| Average Length Paved per Day: | 4500-7000' |

Description of Paving Train:

CMI Slipform Paver
CMI Belt Spreader
CMI Tube Finisher
Barton (CMI) Spray Cure Machine
Mengel Built Tube Assembly
Mengel Built Giant Depressor Rig
Mengel Built Finisher Cart

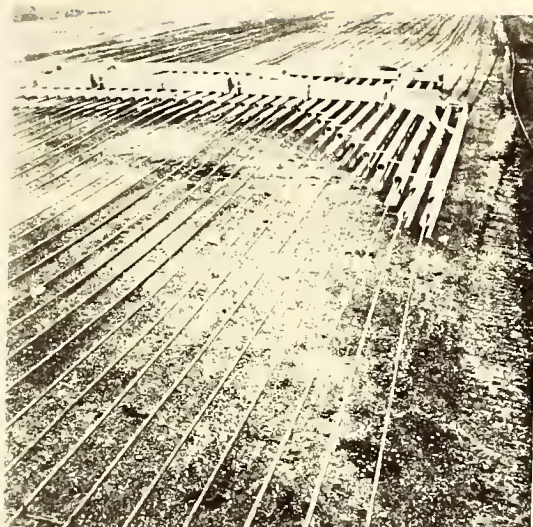
Description of Job Method:

Steel was brought directly from the supplier to the site in 6 semi trucks. It was deposited in two rows on the prepared surface 8 ft in from each side of the roadway. A crew of steel laying men then distributed, lapped and tied the steel on the subgrade. The steel was fed through the tubes at the beginning of the operation and attached to the spreader. Concrete was poured and distributed around the steel.

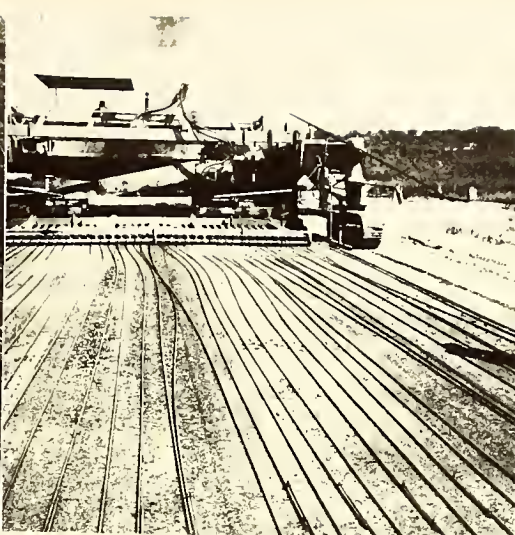
A rotating notched wheel behind the spreader was used to deposit the tie bars. This operation was followed by the giant drum with spiral blades already set to 3" to depress steel to the final position. This unit used no power; the movement of the paver rotated the drum. See Figure 46. The slipform paver finally finished the slab and automatically installed polyethylene fiber as in Job 3. The slab was finished with tube float and by a number of finishers riding on a self-propelled cart. The slab was finally spray cured with white pigment. See Figure 60.

Comments:

This paving operation was unique and interesting. The contractor, by good planning, was able to meet specifications with equipment that was not power-driven. He did not use any storage yard equipment or labor and thereby reduced his steel labor to only 24 men. It was not possible to observe



1.



2.



3.



4.

Figure 60

Enumerated Procedure for Using Tube Assembly

1. Steel is fed through tubes and
2. the complete unit is attached under the belt-placer where concrete is spread around the steel.
3. Behind the belt-placer is a rotating drum for inserting tie bars.
4. The slab is finished by a slipform mover.

his steel placing crew because, due to adverse weather, it was not working on the days that the site was visited.

Job 8: Mesh Depressor - CMI

Job Details

Location:

U.S. 41, Boswell, Indiana

Job Specifications:

8" CRC experimental project reinforced with mesh by the use of a mesh depressor, with 2-1/4" straight crown, 24 ft wide, steel being positioned at mid-depth.

Steel Specifications:

| | |
|-------------------------------|---------------------|
| Length of sheet | 34' |
| Width of sheet | outer sheets 8'6" |
| | middle sheets 7'10" |
| Spacing of Longitudinal Wire: | 4" on centers |
| Diameter | 1/2" |
| Spacing of Transverse Wire: | 12" on centers |
| Diameter | 1/4" |
| Total Weight of Sheets | 800 lb. |
| Length of End Laps | 16" |
| Stagger | 4' |
| Length of Overlap of Sides of | |
| Longitudinal Wire | 3" |
| Method of Securing: | Wire tied at Laps |

Hauling and Placing of Steel:

Storage Yard Equipment: None, contractor used drop

system in which a day's run could be stored in case of emergency. Steel was supplied from manufacturer in 6 semis. When he brought in a truck load, there would be an empty truck to be picked up.

Hauling Equipment: Six semi trucks

Steel Placing Equipment: One semi truck; one McMahan steel sling and one mobile crane.

Labor to Move Steel to Site:

Number
0

Labor to Lay Steel:

| | |
|---|------------------|
| Mesh laying operation | 6 |
| Crane operator | 1 |
| Oiler | 1 |
| Tieing crew (also operate chair machine) Man 2 | 6 |
| Truck driver | 1 |
| Foreman | <u>1</u> |
| Grand Total | <u><u>16</u></u> |

Average Length of Steel Laid per 10 hr. Day: 4500'

Concrete Production: Central Plant

| | |
|---------------------------------|------------------|
| Volume of Plant | 450 cu. yds./hr. |
| Volume of Hauling Units | 8-1/2 cu. yds. |
| Number of Hauling Units | 11-13 |
| Average Quantity Paved per Day: | 2800 cu. yds. |
| Average Length Paved per Day: | 4500' |

Description of Paving Train:

CMI Belt Spreader Placer in front of which was attached a set of rollers connected to a sled type bridge to hold steel in position.

CMI Mesh Depressor Attached to the front of the slipform paver.

CMI Slipform Paver.

CMI Tube Float Machine.

Barton (CMI) Broom and Spray Cure Machine.

Description of Job Method:

A truck loaded with mesh was brought in and hitched to a mobile crane. The mobile crane was equipped with a McMahan "steel sling" with four heads which were air operated. Each head had four hooks. Two men on the truck hooked on a mesh and the crane carried it to the subgrade where four men positioned and lapped it. They also did the preliminary tying.

Two methods of placement were used on this job.

1) chair supports and 2) mesh depressor.

For chair support, a McMahan built self-propelled chair machine raised the mesh above the subgrade by a roller and four workmen slipped chairs under the mesh as the machine moved forward. Two other men came from behind and tied the steel. The chair men also went back to help with tying when the machine was idle.

For the mesh depressor, a series of rollers was attached to a sled type of unit and welded to the

front of the belt placer. These rollers raised the mesh to about 6" above the subgrade.

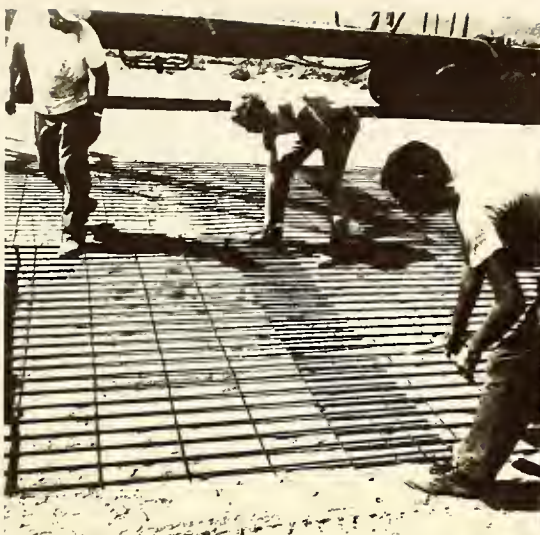
Concrete was deposited and spread by the belt placer around the steel. The CMI mesh depressor, using vibration, with very small amplitude (1/8") and pressure, depressed the steel to mid slab depth. The slipform paver then finished the slab. Two finishers using long hand floats finished the surface. They were followed by a CMI Tube Finisher. A combination transverse brooming machine and spray cure machine put in the final finishing.

Comments:

As expected, the labor expended with the use of mesh was smaller than that used for installing bars. The contractor further cut labor by getting his mesh directly from the supplier instead of first stockpiling it in a yard and then bringing it to the site.

The contractor applied a formula to determine the number of trucks to use in supplying concrete as the distance from plant varied. He used 4 trucks per mile plus one. Figures 40 and 61 show pictures of the operation. This project was an experimental one, and was the first use of mesh depressor with slipform in Indiana. The contractor was happy about it and felt that it was the beginning of things to come.

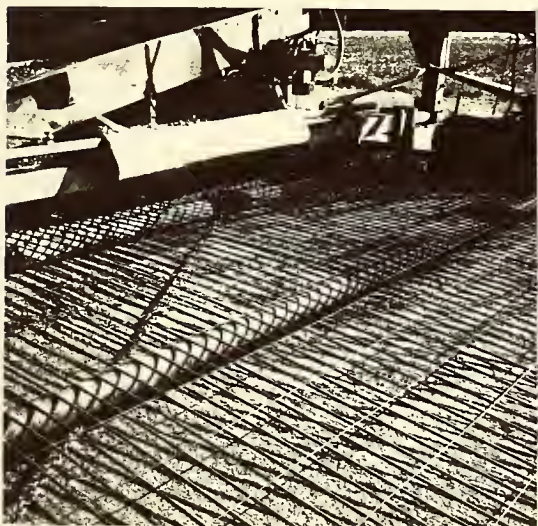
The operation was satisfactory to the State Highway Commission. Another contractor has asked for permission to use the technique on an interstate job in Indiana.



1.



2.



3.



4.

Figure 61

Enumerated Procedure for Using Mesh Depressor

The steel is carried by a sling to the subgrade where

1. it is lapped with a template and tied.
- 2 & 3. A contractor-built machine raises the mesh above the subgrade where the concrete is poured around it and
4. is finally depressed to position by the mesh depressor.

Analysis of Steel Placement Operation

The method of placement has been completely described above. The series of rollers picked the steel up from the subgrade. Five men were actually involved with this operation, besides the two on the semi truck. One man (Man 1) moved the truck and also helped four men on the subgrade unhook the steel from the crane. Two of the four men (Man 2 and Man 3) did the tying, and the other two either helped with the lapping or remained idle.

During the course of the observation the air operated hook broke down for about 3 minutes. This was considered an unproductive occurrence and was included in the calculations presented here. Tables 16 and 17 show the productive and unproductive times of the mobile crane and reinforcing steel setters respectively. As seen from Table 17, Man 4 and Man 5 were idle for substantial percentages of time (compare with Table 14). Four such men were used on Job 6 to position the mesh, and the analysis suggested that the contractor might eliminate two of them. This has already been done by the contractor on Job 8. Although this contractor used more labor than did the contractor on Job 6 he was working with one crew for the chair operation and other crew for the sled support operation. If the chair support men were eliminated, the Job 8 contractor would only need 10 men to lay the steel. It appears that he has cut his labor to the minimum possible, and is still able to lay 4500 ft of heavy mesh per day.

Table 16. Times Spent on Various Activities by the
Mobile Crane

| | |
|----------------------------|--------------------------------------|
| Job No.: <u>8</u> | Location: <u>U.S. 41 N., Indiana</u> |
| Contractor: <u>McMahan</u> | By: <u>oto</u> |
| Film No.: <u>4</u> | Date: <u>9-29-70</u> |

| Activity | Productive (%) | Unproductive (%) |
|---------------------|----------------|------------------|
| Return to Stockpile | 18.10 | |
| Load Steel | 21.27 | |
| Carry Steel | 14.02 | |
| Position Steel | 21.27 | |
| Down Time | | 25.34 |
| % Productive | 74.66 | |
| % Unproductive | | 25.34 |

| Average Cycle Time (secs.) | |
|----------------------------|-------|
| With Down Time | 60.27 |
| Without Down Time | 45.00 |

Table 17. Times Spent on Various Activities by Steel Setters and Tiers, Job 8*

| Activity | Productive (%) | | | Unproductive (%) | | |
|----------------|----------------|------------|------------|------------------|------------|------------|
| | Man 1 | Man 2&3 | Man 4&5 | Man 1 | Man 2&3 | Man 4&5 |
| Position Steel | 25.33 | 31.82 | 26.00 | | | |
| Lap Steel | 9.00 | | 3.66 | | | |
| Tie Steel | | 22.73 | | | | |
| Idle | | | | 47.00 | 27.27 | 51.67 |
| Down Time | | | | 18.67 | 18.18 | 18.67 |
| % Productive | 34.33 | 54.55 | 29.66 | | | |
| % Unproductive | | | | 65.67 | 45.45 | 70.34 |

* No identifiable cycle. Man 2 & 3 are the steel tiers.

Summary of Key Job Data

Table 18 summarizes the job details.

Commentary

Setting reinforcing steel for highway slipform paving is a complicated process. Serious difficulties were encountered when attempting to record the operation with a time lapse camera. Many actions were going on at the same time, and many people were moving around. This meant that the camera could not focus on one action without losing track of the others. In some instances, the analyst had to observe as many as 12 people who were doing different things at the same time, or were continuously shifting their positions. To keep track of one man in this group, it was necessary to make repeated reviews of the film and attempt to distinguish the man from his fellow workers. The findings presented in this report, except where otherwise noted, have been confined to those instances when the workers could be definitely identified.

Space limitation on the job site was also a major problem in the field studies. In many cases a location that would permit a view of all the operations was so distant that the required detail could not be obtained, even with the aid of the zoom lens on the camera. The solution, admittedly a compromise, was to observe a part of the action for a limited period of time and assume that this sample was

Table 18. Summary of Details

| Job Number State | 1 Iowa | 2 Iowa | 3 North Dakota | 4 Minnesota | 5 Minnesota | 6 Indiana | 7 Illinois | 8 Indiana |
|----------------------------|--------------------|----------------------|-------------------|-------------------|--------------------|--------------------|------------------|--------------------|
| Type of Pavement | CRC | CRC | CRC | CRC | Jointed | CRC | CRC | CRC |
| Slab Thickness | 8" | 8" | 8" | 8" | 9" | 9" | 8" | 8" |
| Concrete Production | Central Plant | Central Plant | Central Plant | Central Plant | Central Plant | Central Plant | Central Plant | Central Plant |
| Forms | Slipform | Slipform | Slipform | Slipform | Slipform | Side Form | Slipform | Slipform |
| Crown | 2-1/2" Par. | 2-1/2" Par. | 1-1/2" Par. | 2.88" Par. | 1-1/2" Par. | 2-1/2" Str. | 2-1/4" Str. | 2-1/4" Str. |
| Position of Steel | 2-1/2" - 3-3/8" | 4" | 4" | 4" - 5" | 3-1/2" | 4" + 1/2" | 3" | 4" |
| Type of Reinforcement | #5 Def. Bars | #5 Def. Bars | #5 Def. Bars | #5 Def. Bars | Welded Wire Fabric | Welded Wire Fabric | #5 Def. Bars | Welded Wire Fabric |
| Placement Method | Rebar Installer | Rebar Installer | Rebar Installer | Chair Supports | Mesh Depressor | Mesh Depressor | Tube Assembly | Tube Assembly |
| Longitudinal Reinforcement | Plus Tube Assembly | | | | | | Plus Spiral Drum | Mesh Depressor |
| Size | 5/8" | 5/8" | 5/8" | 5/8" | 1/4" | 1/2" | 5/8" | 1/2" |
| Spacing | 6" | 6" | 6-1/2" | 5.4" | 6" | 4" | 6-1/2" | 4" |
| Length | 60' | 42' | 60' | 60' | 18' | 24' | 40' | 34' |
| Lap | 16" | 18" | 18" | 18" | None | 16" | 16" | 16" |
| Lap Stagger | 6' | 4' | 4' | 4' | None | 4' | 3' | 4' |
| Transverse Reinforcement | None | None | None | Bar | Mesh | Mesh | None | Mesh |
| Size | - | - | - | 5/8" | 1/4" | 1/4" | - | 1/4" |
| Spacing | - | - | - | 4" | 12" | 12" | - | 12" |
| Length | - | - | - | 13.75' | 11' | 6' | - | 7'10" - 8'6" |
| Lap | - | - | - | 2' | None | - | - | 3-1/2" |
| Wire or Bar Connection | - | - | - | Clipped | Welded | Welded | - | Welded |
| Weight per Sheet of Fabric | - | - | - | - | Not Available | 4000# | - | 8000# |
| Tie Bars | - | - | - | - | - | None | - | None |
| Size | 1/2" | 1/2" | 5/8" | None | 5/8" | - | 5/8" | - |
| Length | 36" | 36" | 30" | - | 30" | - | 30" | - |
| Spacing | 42" | 36" | 30" | - | 30" | - | 30" | - |
| Storage Yard Equipment | (1) Mobile Crane | (1) Hough end Loader | (2) Mobile Cranes | (2) Mobile Cranes | (1) Mobile Crane | - | None | None |
| Hauling Equipment | (1) Semi-truck | (2) Semi-trucks | (2) Semi-trucks | (2) Semi-trucks | (2) Semi-trucks | (2) Semi-trucks | (6) Semi-trucks | (6) Semi-trucks |
| Labor to Move & Lay Steel | 31 men | 28 men | 32 men | 40 men | 18 men | 15 men | 24 men | 16 men |
| Length of Steel Laid | | | | | | | | |
| per 10 hr. Day | 5300' | 6000' | 4000' | 4500' | 2400' | 3200' | 5200' | 4500' |
| Length Paved per Day | 3600-4000' | 4000-5000' | 3600-4000' | 4700' | 3500' | 3000' | 4500-7000' | 4500' |

representative of the normal working pattern for the
workers and machines.

PART IV

EVALUATION OF RESEARCH FINDINGS

PART IV - EVALUATION OF RESEARCH FINDINGS

Discussion of Findings

Slipform Paving

The statements made herein concerning slipform pavers are largely based on statements supplied by state officials and contractors. Their judgement reflects their years of experience with slipform paving and the findings of tests on slabs which have been constructed in this manner.

Many state highway officials now believe that slipform pavers can produce concrete slabs of quality equal to or better than that obtained by hand finished, form set methods. This belief has been supported by core tests and by the service performance of thousands of miles of thumpless, smooth, and trouble free slipformed pavements. Many officials also believe that slipformed pavements are constructed at lower cost than the conventional side form pavements. Savings of as much as \$0.50 per square yard over conventional side form paving have been reported in Iowa, Colorado and California, and in other states.

Many contractors and highway officials believe that slipform pavers can successfully construct most of the interstate highways as they are designed today. There are

still some problems in paving ramps and parabolic crowns, but these difficulties are gradually disappearing as more and more states adopt uniform width ramps and straight crowns. Contractors are then able to slipform ramps along with the main line paving instead of using side forms. The use of straight crowns eliminates the extra labor which the contractor otherwise expends in installing a parabolic crown after slipforming.

One major problem, seemingly a universal one, is the proper consolidation of the slipformed pavement. Vibration equipment manufacturers lack adequate information in this area. The empirically derived vibration techniques which had been used successfully for side form paving do not appear to be equally valid for slipform paving. Concrete failures attributable to improper concrete consolidation have been experienced in some states, including Texas and Ohio.

Another problem area is the measurement of depth and smoothness of a slipformed pavement. The need for accurate and non-destructive methods of measurement is becoming more critical as greater mileages of slipform pavements are laid annually. There are many reasons for seeking to improve measurement techniques, not the least of which is the accurate determination of pay quantities. Work has been performed in this area at Ohio State University, the Illinois Institute of Technology, General Motors Research Laboratory, Portland Cement Association, and elsewhere. The ideal equipment is still far from being a reality.

Continuous Reinforcement

The findings relating to continuous reinforcement of pavements are based on literature reviews, answers to a questionnaire (Table 3), and field observations.

Increasingly, states are using continuous reinforcement on their state and interstate highway systems (55). This is evidenced by comparing the 79 miles of equivalent 2-lane miles constructed between 1938-58 to the 7,524 miles of equivalent 2-lane miles which had been constructed by the end of 1969. This fast growth has been augmented by the development, acceptance and use of mechanical steel placing machines. The use of these machines has substantially reduced the amount of labor required to lay reinforcing steel (Table 18). Many states have modified their specifications to permit steel tolerances which are compatible with these mechanical techniques (Table 3).

The placing of steel on chair supports still requires a substantial amount of labor, even when mechanical aids are used (See Job 4 analysis and Table 18). Many states have eliminated both chair supports and transverse steel in CRC pavement. These changes have led to substantial reductions in the material and labor costs, which have been reflected in the bid prices (see Table 3). They have also made it possible to lay record lengths of continuously reinforced pavement per day (see Jobs 1, 2 and 7).

The analyses of the time lapse photography records suggested that the efficiency of the steel laying operation could still be improved for many contractors. It appeared that some contractors did not plan their operations in adequate detail, or did not carry their plans down to the level of the labor force. These planning inadequacies contributed to several delays and idle periods.

Only a few years ago, the placement of more than 2,000 ft of continuous reinforcement per day was a rarity. Even today, a contractor who is able to lay 3000- or 4000-ft of continuous reinforcement per day may not be too concerned about trying to improve his methods and productivity. However, these subjects may still warrant his careful attention. An example was seen in Job 2 where groups of reinforcing steel setters were waiting for each other and the work arrangement required one crew to travel distances far greater than those travelled by another crew. Admittedly, the contractor in question still laid 6000 ft of continuous reinforcement per day, but a job review might have simplified the working process so that it could be performed with less effort and in less time. The competitive contractor cannot afford to sit back and admire what he has already achieved; progress requires that he continually strive to improve his past performances.

The contractors on Jobs 7 and 8 were able to reduce the requirements for labor and equipment by eliminating the

storage yard labor, equipment and space. They both used the "drop system" whereby the supplier brings the steel to site as needed. Of course, this makes the contractors' daily production dependent on the performance of his steel supplier, but careful scheduling can reduce truck delays to a minimum.

There are three mechanical methods now available on the market which have been used to the satisfaction of many state highway officials. The mesh depressor, three types of which are now available, has been used more extensively than the rebar installer (see Table 18). However, some faults have been discovered in slabs placed by the mesh depressor. These faults have occurred mainly at the laps (see Table 3). Some persons have attributed them to improper lap, because some mesh depressors tend to drag the steel along as they move forward. Other persons have attributed the faults to improper concrete consolidation at the laps.

The rebar installer has generally performed satisfactorily in the states in which it has been used (see Table 2). The tube assembly has not been consistently satisfactory when used by itself. However, when it is augmented by the rebar installer (Job 1) or by a comparable device (Job 7), it has apparently performed satisfactorily.

Conclusions

The slipform paver is not yet fully perfected. Further modifications in its design and operation are still required to ensure proper consolidation of the concrete. Pavement

failures in Texas, Ohio, and other states have been attributed to improper concrete consolidation. Equipment design attention should be directed towards ways of obtaining better and more uniformly densified pavement slabs. The empirical procedures for pavement consolidation have not proved valid for slipform pavement construction. The solution to the problem may involve a type of vibrator which would be unique to the slipform paving operation, or it may merely require some modifications to the commercially-available types of vibrators.

Operator experience is another important factor in the proper consolidation of slipformed pavements. Operator inexperience can cause many paving delays. These can affect the quality of the concrete prior to consolidation to such an extent that it cannot be properly consolidated by the slipform vibrators. It would be highly desirable to develop an improved version of the slipform paver, including suitably modified vibration equipment, wherein the possibilities of pavement inadequacies resulting from human errors were substantially reduced.

This study has demonstrated the need for a rational understanding of the consolidation of slipformed concrete. Efforts have been made in this direction but no satisfactory solution has yet been found. The search must continue if slipform paving is to achieve the ultimate goal of providing the highway user with the highest quality concrete pavement, at least cost.

On each of the jobs studied, the contractor experienced one form of delay or another. Equipment breakdown is an unpredictable cause of delay, which the contractor tries to avoid through careful maintenance and sound operating procedures. The success of the contractors' efforts in this area can be judged from the frequency of occurrence of equipment breakdowns during the construction season. Most of the job delays were the consequences of job planning deficiencies. In one instance (Job 1) the steel setters had no specific cycle of operation and simply moved from one side of the equipment to the other. The result was an excessive loss of productive time. In Jobs 2, 3 and 4, one or two groups of workers on each job travelled distances far greater than those travelled by the other groups. As still another example, in Jobs 3, 5, 6 and 8, the steel placing labor was assigned to ancilliary duties which interfered with their primary duties.

One of the consequences of delay was clearly demonstrated in Job 5. The delay in concrete distribution caused a halt in the paving operation, and made it necessary to move crews from one place to another. Such delays are very costly to the contractor. There appear to be enough potential areas of improvement in the ways that contractors execute their field jobs to warrant more critical planning evaluations of their operations. When people are brought together to perform a specific task as a group without adequate prior

orientation, they are seldom able to coordinate their efforts into one purposeful end result.

It is pertinent to ask what management can do to improve the present systems. The first step is to study the systems in current use, and try to find out where deficiencies exist. Once these have been located, alternative means for correcting them can be analyzed. The time lapse photography technique is an aid in this process. Jobs can be planned in detail so that efficient working cycles can be identified and made known to the foreman, who will then convey the ideas to his men.

The presently available mechanical methods for depressing steel are not yet fully perfected, but additional improvements can be expected to come with time. In the opinion of the author, the rebar installer is the best machine now on the market. It can be used to depress both bars and mesh, and has consistently met specified tolerances for steel positioning in all of the states where it has been used.

The paving operation of the future may utilize a moving mold which extrudes threads of reinforcement on site, automatically cools them, and feeds them continuously to the slipform paver at the same rate that the concrete can be supplied to the paver. For the present, however, we must rely on the available equipment. Even though this has not completely met the desires of all highway officials, it is certainly better than the manually executed chair support .

method. The savings from the use of mechanical steel placement methods are somewhat conjectural because of the limited experience with this type of equipment (Table 3). However, the potential savings are sufficiently attractive to warrant the interest of highway officials. Innovations should be encouraged, for in this direction lies continuing progress.

Recommendations

1. The state should consider the use of uniform width ramps. This change, which has been accepted by many states around the country makes it easier for the ramps to be slipformed. The gains made in mainline paving can thereby be extended to ramp paving. Some states use a 16 ft width, while others use a 24 ft width with the traffic lanes delineated with paint markings.
2. The state should initiate research to develop an accurate technique for checking pavement smoothness and thickness.
3. The state should initiate research to identify the sizes, weights, spacing, lengths, etc., of vibrators which give the best consolidation for reinforced concrete pavement.
4. The new equipment for steel placing is recommended for use, especially the rebar installer. It is suggested that the state request the presence of a representative of the equipment manufacturer during the initial use of any new piece of equipment to ensure its proper use.
5. The state should modify its steel installation specifications to accomodate the tolerances attainable by these new techniques.

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